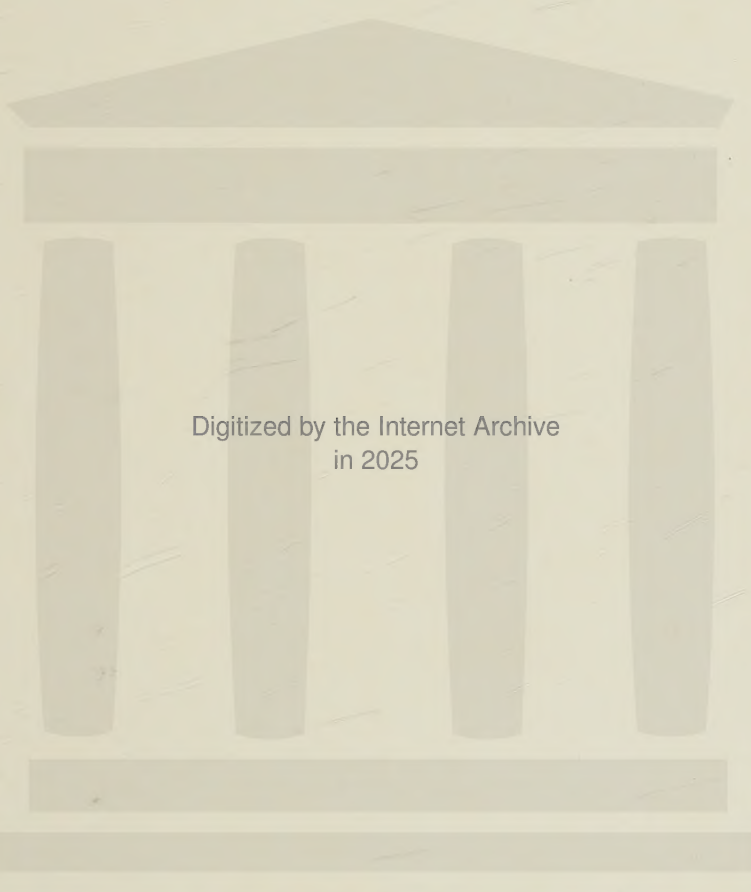


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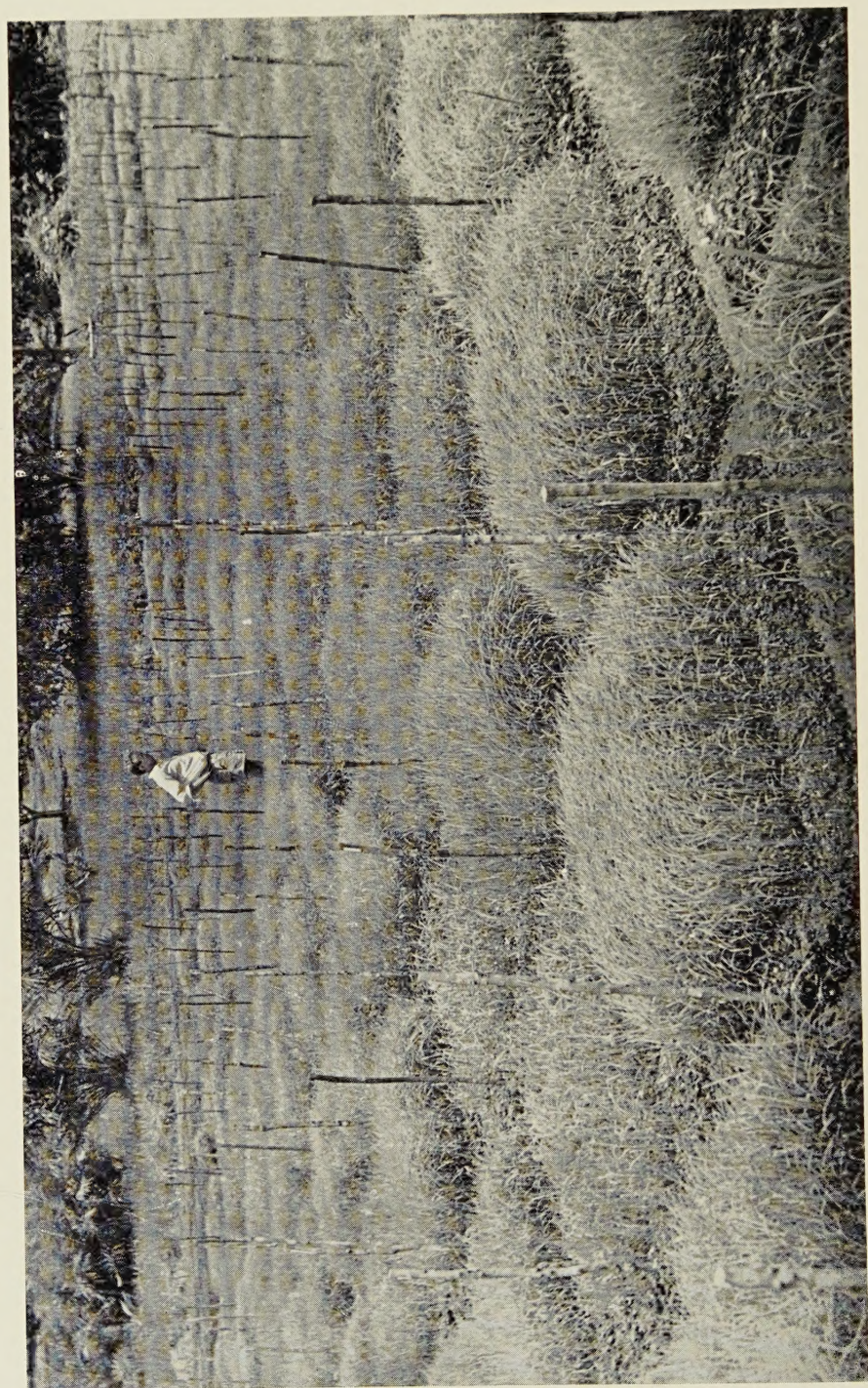
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WEST AFRICAN RICE RESEARCH STATION
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ANNUAL REPORT

of the

WEST AFRICAN
RICE RESEARCH
STATION

1959

Price 2/-

Published on behalf of the
West African Rice Research Station, Rokupr, Sierra Leone,
by the
Crown Agents for Oversea Governments and Administrations,
4 Millbank, London, S.W.1

1961

To be purchased from either of the two agencies overleaf and from
the Government Printing Department, Freetown, Sierra Leone.

**A POISONOUS INSECTICIDAL SOLUTION
HAS BEEN USED IN BINDING THIS BOOK**

*Printed by Eyre and Spottiswoode Limited
Her Majesty's Printers
at The Chiswick Press, London, N. 11*

ADMINISTERING AUTHORITY
THE SIERRA LEONE GOVERNMENT

Director of Agriculture :

J. W. D. GOODBAN, O.B.E., M.A., DIP.AGRIC., A.I.C.T.A.

ADMINISTRATIVE AND PROFESSIONAL STAFF

At 31st March, 1960

Officer in Charge :

H. D. JORDAN, B.SC., A.R.C.S., A.I.C.T.A.

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Soil Microbiologist :

M. G. R. HART, B.SC., PH.D.

FOREWORD

by

SIR MILTON MARGAI, Kt., M.B.E.

Prime Minister of Sierra Leone

1959 represents the first full year in which the Rice Research Station has been fully staffed, and it can be truly said that the Station has really got into its stride.

At a time when pressures of land usage and increasing population urgently underline the necessity for the production of more food, and with such a large proportion of the world depending upon rice as a staple article of diet, it is very satisfying to see the progress which is being made at Rokupr.

Apart from the fundamental research which has been carried out, and which is rapidly gaining for the station and staff a high international reputation, much of practical significance to Sierra Leone and the other participating Governments has been accomplished. The release of new high yielding varieties represents an immediate and visible contribution to the agriculture and economy of West Africa, and should the milling experiments described be ultimately applicable to full scale practice, a further achievement of great value will have been made.

Once again, we in Sierra Leone are pleased to express our gratitude to other West African Governments, and for the Colonial Development and Welfare contributions, which have made this work possible.

INTRODUCTION

Last year a brief general discussion of the agricultural background of rice growing in West Africa was used to introduce this report. It is proposed this year to mention more specifically some development schemes in the contributing territories and to discuss the part that the West African Rice Research Station is playing in these.

Rice growing is developing rapidly in the Gambia, which has a very great potential in this respect. Much of our work in the past is almost immediately applicable to the middle reaches of the Gambia river, where the Agricultural Department has a station for local rice work and where mangrove and grass lands are being brought into cultivation. Towards the mouth of the river salinity is a problem and any major developments here in the future will have to take account of current investigations at Rokupr. The Gambia Rice Farm is situated above the influence of saline tide water and has done good work on the practical development of fresh water swamps. One problem that has arisen there is that of a dry season crop under irrigation, and it is thought that present work on photoperiod-insensitive short term rices will be of assistance in this respect.

Sierra Leone, having the station within its bounds, has been able to take immediate advantage of the improvement programme and to distribute new varieties to farmers with little further trial. The development of the deeply flooding grasslands in the south of the country has made full use of improved floating rices, and further work in progress should bring increased benefits to this area. Development of the large areas of saline mangrove land along the coast awaits the introduction of suitable techniques based on the results of soil investigations in progress. The other large areas for development are the inland riverain flood plains. The problems of these are not so straightforward, but the fundamental studies on the chemistry and fertility of flooded soils which have now been started are expected to be of great importance when their full development is considered.

Ghana is also at the present time engaged in an effort to increase rice production. In the far north, on the granite soils, small scale rice production has been shown to be very successful in conjunction with land planning schemes. Varieties introduced into West Africa through Rokupr are doing well but, as rice is not a staple food in the area at present, other crops take priority in the agricultural system. The consequent tendency for late planting of rice has an adverse effect on yield, and it is thought that the introduction of quick maturing photoperiod-insensitive varieties, the development of which is now being studied, should considerably raise production. The problems on the alkaline soils with low rainfall of the Accra plains are different from those of other parts of West Africa, and agronomic work in this area is being undertaken by the University College of Ghana at its field stations of Nungua and Kpong. The West African Rice Research Station is in close contact with this work and assists with advice and the supply of varieties. Early photoperiod-insensitive varieties are again expected to be of considerable value in such schemes as that now being implemented by the Ghana Government at Dawhenya, where double cropping under irrigation is envisaged.

Nigeria, due to the size of the country, has the largest potential for rice development of the contributing territories. Advice and assistance is

channelled through the Federal Rice Research Station at Badeggi with whom this station works in close conjunction. Mention has been made in the last report of the Sokoto river valley, where recent trials are showing that our standard floating rice and more recent introductions will give greatly increased yields over local *glaberrima* rices. There are many areas elsewhere where floating *glaberrima* rices are at present grown, for example the deep flooding parts of the Niger and Benue flood plains, and development of these is expected to take full advantage of this earlier work. Another enormous area, development of which is envisaged, is the Niger delta. Considerable local agronomic work will be necessary there, but the experience of Rokupr in rice growing on similar types of land should be of great value, and an experimental programme, based on our advice has already been started in order to evaluate the local problems.

Apart from these few major development schemes in the contributing territories, which have been only briefly mentioned, rice growing is developing rapidly throughout West Africa, and our more basic work, such as the fundamental soil studies and the investigations of the physiology of the rice plant, should lead to greatly increased production in the future. It should perhaps be stressed however that the function of this inter-territorial station is research and advice, and that the practical implementation of recommendations depends upon the extension services of the Ministries of Agriculture of the territories. The importance of sound extension services to implement the results of research cannot be too strongly emphasized.

The problem of increasing world population and food supply has been much to the forefront in recent times. With the enthusiasm now being shown by Ministries of Agriculture and the further development of their extension services on modern lines it is felt that the West African Rice Research Station can make a very real contribution to solving this problem in West Africa, and that many results of work at the station will form a basis on which improvement can be made in other parts of the world.

The continuing support of the contributing governments, the co-operation of the Sierra Leone Government in whose territory the station lies, and the interest in the work shown by scientists in all parts of the world will augur well for the expansion of the work of the station and its impact on the economy of West Africa.

ADMINISTRATION

As last year, the details in this section of the report cover the new financial year, from April 1959 to March 1960.

STAFF

Administrative and Professional

Mr. H. D. Jordan, Officer-in-Charge, went on leave at the end of December and did not return until after the end of the administrative year.

Dr. P. R. Hesse, Soil Chemist, was on leave from mid-July until mid-November. During Mr. Jordan's absence he acted as Officer-in-Charge.

Dr. M. G. R. Hart, Soil Microbiologist, went on leave in mid-June and returned in late October.

Dr. E. H. Roberts, Plant Physiologist, returned from leave at the beginning of August, and Mr. R. Q. Craufurd, Plant Breeder, later the same month.

Mr. A. J. Carpenter, Plant Breeder, and Mr. J. W. O. Jeffery, Soil Chemist, were in post for the whole of the year.

Mr. J. C. Rippey of the Sierra Leone Department of Agriculture left on resignation in May. The post of Station Manager was then filled from the Department of Agriculture by Mr. S. A. Kawa followed by Mr. S. A. Jabati until December, since when it has been vacant.

Mrs. Enid M. Jeffery has been temporarily assisting in reorganization of the library since December.

Clerical and Technical

The clerical staff position remains unchanged and unsatisfactory. It has so far been impossible to obtain a full strength of fully qualified staff and this is still hampering the preparation of reports and technical papers, as well as throwing extra work on Professional and Administrative staff.

Two further Laboratory Assistants were appointed in September and November respectively and this has brought the laboratory staff to full strength for the first time.

The field staff position has remained satisfactory though it is now felt that extra assistance would be desirable at certain busy seasons of the year.

Unestablished staff and Labour

Laboratory Attendants, Farm Guards and minor employees remain at full strength and the labour force continued to average 110 throughout the year.

PUBLICATIONS

Brief Quarterly Progress Reports were issued in cyclostyled form and the 1958 Annual Report was published during the year.

Periodic Scientific Report No. 10 dealing with nutritional values of rice was issued.

The following papers have been published:

"Geotropic and Morphological Alterations in Rice Seedlings caused by Plant Growth Regulators", E. H. Roberts, *Nature*, **183**, 1197. (1959).

"Sulphur Oxidation in Tidal Mangrove Soils of Sierra Leone", M. G. R. Hart, *Plant and Soil*, **11**, 215. (1959).

"The Viability of Cereal Seed in Relation to Temperature and Moisture", E. H. Roberts, *Annals of Botany*, N.S. **24**, 12. (1960).

"Iron and the Eh of Waterlogged Soils with particular reference to Paddy", J. W. O. Jeffery, *Journal of Soil Science*, **11**, 140. (1960).

"The Effect of Gamma BHC on the Growth of Rice Seedlings", E. H. Roberts, *Empire Journal of Experimental Agriculture*, **28**, 133. (1960).

"The Utilization of Saline Mangrove Soils for Rice Growing", H. D. Jordan, *Proceedings of the Third Inter-African Soils Conference*, (1959).

The following paper has been submitted for publication:

"Defining the State of Reduction of a Paddy Soil", J. W. O. Jeffery, *Journal of Soil Science*, September, 1960.

TOURING AND VISITS

Mr. Jordan attended the Sixth Nigerian Agricultural Technical Committee meeting at Ibadan in April for liaison in rice research.

At the beginning of September he started on a ten day visit to Ghana, where he visited potential rice schemes near Accra and in the Northern

Province. This was followed by four weeks in Nigeria where the variety trials at Birnin Kebbi were examined and existing and potential rice lands in the Lowlands Division of Plateau Province, in the Maiduguri and Chad area and in the Yola area of the Benue were visited. A short call was also paid on the Federal Rice Research Station at Badeggi. These visits were made mainly to see local conditions of rice growing, to see the problems involved and how the research programme of the West African Rice Research Station is suited to these, and for general discussions.

In November Mr. Jeffery represented the station at the Third Inter-African Soils Conference at Dalaba in the Republic of Guinea.

While on leave Dr. Roberts read a paper entitled "The Prediction of Viability in Cereal Seeds" to the Society of Experimental Botany at their Easter Conference at Swansea. He also visited the University College at Aberystwyth, the Grassland Research Institute at Hurley, and the Pest Infestation Laboratory at Slough. Mr. Craufurd visited the Tropical Products Institute while on leave.

Following on discussions initiated at the Sixth Nigerian Agricultural Technical Committee meeting the previous April, arrangements were made for Rokupr research officers to advise on development of the Niger Delta, and towards the end of March a combined visit was made by Messrs. Hart, Carpenter and Jeffery. As a result of this visit they were able to suggest a three year experimental programme which will test the potentialities of the area and expose any problems which will have to be solved. Nigerian governments have decided to implement this programme, at least in part.

Regular visits were paid within Sierra Leone to the Station extension areas at Mandu, Kontobe, Torma and Wellington. Dr. Hesse toured the country at the beginning of the year arranging for rainwater collections and Mr. Carpenter visited the main upland rice growing area in September.

VISITORS

His Excellency Sir Maurice Dorman, K.C.M.G., Governor of Sierra Leone, paid three visits to the station during the year. In November he was accompanied by Lady Dorman and by the Honourable I. B. Kamara, Minister of Trade and Industry in the Sierra Leone Government; in December he was accompanied by the Honourable H. J. Demby, Minister of Natural Resources in Sierra Leone and in March he was accompanied by Mr. and Mrs. Bostock from the United Kingdom. On the December visit His Excellency made the first official landing on the nearby airstrip, which had been prepared in anticipation of a visit from H.R.H. Prince Philip, and he opened the annual meeting of the Station Committee with a brief address. In March he came to meet H.M. Consul General at Dakar, Mr. J. H. A. Watson and Mrs. Watson, who landed on the airstrip on arrival from Dakar. Lady Dorman paid a brief visit to the station in January accompanied by Mr. J. Thompson from Ghana.

The Premier of Sierra Leone, Sir Milton Margai, Kt., M.B.E., paid a brief call at the station in December.

In May, the Honourable Victor Mukete, Minister of Research and Information in the Federal Nigerian Government, spent a few days on the station, and in July the Sierra Leone Minister of Natural Resources, the Honourable H. J. Demby, stayed for a few days likewise.

Visitors from the United Kingdom included Mr. D. Rhind of the Colonial Office who spent a few days at Rokupr in October, Dr. Herbert Greene from Rothamsted who stayed on the station for a short period after the Third Inter-African Soils Conference, Mr. A. F. Williams of Oxford, Mr. G. B. Hony and Miss V. Waldock.

From further afield Mr. Chaim Gvati, formerly Director General of

Agriculture in Israel visited in July, Mr. J. F. Dekker of the Food and Agriculture Organization of the United Nations in August, Mr. J. J. McKelvey, Assistant Director of the Rockefeller Foundation in September, Mr. M. Manni of F.A.O., Professor Kazuo Furusato and Mr. Yoshimi Mochizuki of the National Institute of Genetics of Japan, Mr. G. Murdoch of the Land Utilization Department of Swaziland and Mr. W. Snoep from Holland in November, Messrs. S. Kraigher, M. Barisic, A. Bozovik and N. Ackovski from Yugoslavia in January and Dr. Jacoby of F.A.O. in March.

The Station Committee met at Rokupr from 16th to 19th December, when Mr. L. G. Heptinstall, acting Administrator of the West African Research Office took the chair. Ghana was represented by Mr. E. O. Oklety and Dr. W. K. Agble, Nigeria by Mr. J. E. Y. Hardcastle, Mr. G. G. Williams and Mr. A. Smyth, Gambia by Mr. J. A. Austin and Sierra Leone by Mr. G. Simpson and Mr. J. M. Dent.

Other visitors from West Africa included Dr. J. M. Waterston, Director of Agricultural Research in the Nigerian Federation, in August, Mr. C. W. S. Hartley, Director of the West African Institute for Oil-palm Research, in September, Messrs. J. H. Pitman and H. Brammer of the Ghana Ministry of Agriculture in October and Mr. Ramaswamy of the Gambia Department of Agriculture in December.

Messrs. C. J. Baughan and J. Clark of the United States Information Services film unit spent a few days on the station at the end of November making a feature film, and Mr. Eldridge of the Shell Company visited the station in December in order to obtain a series of photographs.

In April the S.L.N.S. *King Tom* under command of Lieutenant G. Jarvis, S.L.N.V.F., and accompanied by Lieutenant Commander J. D. Haward, R.N., the Resident Naval Officer, Freetown, paid a courtesy call on the station while on a training cruise in local waters.

MANAGEMENT AND MAINTENANCE

LAND

Discussions with local landowners went on through the year and an agreement to lease was finally signed. Under this agreement a new lease is being prepared which will include the existing station together with a further twenty-seven acres of adjacent swamp land. At the same time the annual rent payable has been revised to a figure more consistent with present values (the old rent being based on 1934 values). The Station now consists therefore of 112 acres of upland and 66 acres of swamp, held on lease for a further 86 years with provisions for extension for another 50 years. The additional swamp land will be brought under cultivation by the station next year.

BUILDINGS

The block of two Farm Guards' quarters started last year was completed and a further block of four built. This completes the programme and all quarters are in occupation.

The new rice store was completed and one section has been air-conditioned so as to preserve the viability of seed over more than one season.

The store and office building started in 1958 have been finished and put into use.

The laboratories were completely rewired during the year and a ring-main system with fused plugs was installed. It is hoped that this will minimize damage to apparatus by fluctuations in the electricity voltage.

Complete redecoration was carried out after the wiring had been completed.

Some modifications were made to the Officer-in-Charge's house, the roof being extended and verandah widened. The house was then redecorated.

The field laboratory has also been redecorated, and extension of the small drying floors adjacent has been made.

A small office building on the station which was originally built by the Sierra Leone Irrigation Engineer was taken over and is being converted into a laboratory with controlled environment for plant physiology experiments.

SERVICES

Dirty water again caused trouble during the dry season and supplies between March and May were spasmodic. A filter system has now been installed and it remains to be seen whether this will cure the trouble.

The electricity supply, which is managed by the Sierra Leone Electricity Department, continued to function, though minor breakdowns and voltage fluctuations appear to be on the increase.

VEHICLES AND MACHINERY

Both the Land Rover and the Bedford lorry were in constant use throughout the year. The former remained in good order but the latter gave considerable trouble and has now been replaced by a lighter Bedford vehicle.

The launch remained in good condition.

The Ferguson tractor has had heavy use with its trailer and with the gang mower. The two Hayter scythes had heavy use also but are starting to give some trouble.

The M.G.6 tractor has been out of action and much of the farm cultivation has had therefore to be done by hand.

STATION UPKEEP

The entrance road as far as the main office and laboratory block has been rebuilt and tarred.

The Angola Oil Palm plantation continued to be used as a source of seed for distribution by the Sierra Leone Department of Agriculture.

Trees have been thinned and stumps removed on part of the upland area of the station in order that upkeep can be more easily and economically carried out. As a result the tractor and gang mower can now deal with a larger area.

EXTENSION AREAS

Station extension areas have now been increased to four.

At Mando, on the Little Scarcies river, trials and observations were again carried out on seasonally flooded grasslands. This site is within easy distance of Rokupr for day visits.

At Kontobe, where two small rest houses have been erected, varietal trials and soil investigations have continued on inland, seasonally wet, less fertile grasslands.

Arrangements are being made to erect a rest house at Torma Bum on the Sewa river in the south of Sierra Leone. Trials are being carried out here on fertile grasslands which flood to varying depth—much of the area needing floating rices.

Three acres of virgin mangrove land have been empoldered at Wellington near Freetown, as three separate units. The work was done by

the Sierra Leone Irrigation Engineer to designs prepared in the Soil Science section at Rokupr. These areas will be used for a study of the soil changes that occur in the field under varying reclamation procedures suggested by current laboratory work at Rokupr.

WEATHER

Twenty-five year records are now available for Rokupr and it has been possible therefore to recalculate the rainfall averages over this period. The total rainfall for the year is just under 117 inches but for a true picture of the climate of Rokupr it is important to examine the distribution of this rainfall, which is concentrated into one peak in the year when much of the precipitation is surplus and merely runs off the ground. The severe dry season is the limiting factor for upland growth, and in this respect therefore the climate can be compared with places of considerably lighter rainfall. In lowlands in all types of climates of course the soil will remain moist for longer than on the uplands: in particular it should be stressed that a part of the farm at Rokupr is on tidal land which relies for its water supply, not on rainfall alone, but on fresh water tidal flooding.

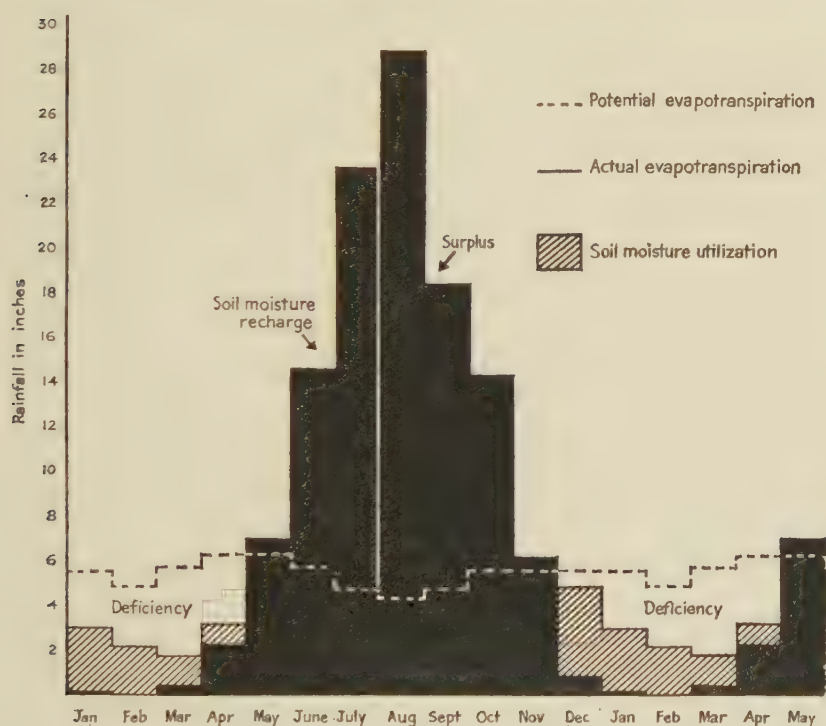


FIGURE I. Average rainfall distribution at Rokupr, indicating type of alternating water surplus and deficiency.

Figure I shows the position graphically. Actual and potential evapotranspiration figures for Rokupr are not readily available so those of Freetown (Thornthwaite's system taken from Johnston's *Staple Food Economies of Western Tropical Africa*) have been superimposed on the Rokupr rainfall figures to show the periods of surplus and deficiency of water. It is not thought that Rokupr figures for evapotranspiration will

differ greatly from those of Freetown but if they do they are likely to be larger and the period of water deficiency thus more pronounced than shown.

The dry season this year was broken by two freak storms, one in January and one in March. Apart from these storms the dry season extended right through April. From May onwards the rainfall followed a normal pattern, although it stopped entirely before the end of November. The general picture is of a well-distributed rainy season on the usual curve, adding up to rather above average rainfall for the whole year. Sunshine hours and mean minimum temperatures were lower than average at the beginning of the year and higher at the end. March had a record low mean minimum temperature and October a record high number of hours of sunshine. Relative humidity, as might be expected, behaved in the converse manner, being higher than average in the early part of the year and lower than average in the later part. Full meteorological records for Rokupr for the year are given in Appendix A.

As rainfall is utilized for leaching of salts when saline land is reclaimed for rice growing, a series of collections and analyses were made. Details are given in the Soil Science section of this report.

AGRONOMY

From time to time there will be problems to be investigated that will fall under this heading. At present however none are in hand. In Sierra Leone, general methods of rice growing are well understood and have received experimental attention in the past. In the other contributing territories there is still a considerable amount of agronomic work to be done, but under the established policy of this station, this is the responsibility of the specialist branches of the local Ministries of Agriculture. The role of Rokupr can only be to advise.

General field procedure at Rokupr is based on the results of former experiments and can be summarized as follows. The farm is cultivated in February and March to a depth of approximately eight inches. The firmer land can be ploughed but the softer parts are hand hoed. Prior to planting, weeds are removed from those drier parts of the farm where they occur and remaining clods are broken down. Nurseries are made on moist land at the swamp edges at the beginning of June. Seed is broadcast at a rate of 750 lbs. per acre and seedlings usually remain in the nurseries for six weeks. Planting takes place from early July to mid September. Two or three seedlings are planted to the stand at a spacing of six to eight inches. Weeding of the standing crop is rarely necessary except on the drier land where one weeding may be needed. Harvest is from November to January. Fertilizers are not normally used in the field though light dressings are given in the nurseries. Drains and bunds are sprayed with technical B.H.C. twice a week after high spring tides in the dry season and experiments are sprayed likewise for one week before and two weeks after transplanting. As a result crabs are infrequent and no longer a cause of trouble in the experimental area.

Farm yields this year have been slightly below those of the 1958-59 season. In multiplication blocks however Ngasein 57, India pa lil 46, Faya and Radin China 4 all gave yields of over 1,800 lbs. per acre, the highest yield recorded being 2,690 lbs. per acre from a fifth of an acre of Ngasein 57. Yields of over 3,000 lbs. per acre were again obtained from some of the promising varieties in plots of about a twelfth of an acre.

Eleven standard varieties are maintained by the Genetic Stock system, whereby multiplication is carried out in stages from single plants bagged annually. These varieties are Faya, Lead, B.G.79, D99, Bolo 108,

Toma 112, Radin China 4, Ngasein 57, India pa lil 46, Kav. 12 and the floating rice Indo-China 53. A total of 290 bushels of pure seed of these varieties was produced and distributed.

Three small polders were constructed on marginal land immediately below the drain from the deep water tank, and these were irrigated during the dry season. It has thus been possible to grow small quantities of rice under irrigation in the dry season in connexion with improvement work on short term photoperiod-insensitive varieties.

BOTANICAL RESEARCH

Now that lists of established rice varieties in all parts of the world have been examined and those that appear to promise well for West Africa have been obtained, it is expected that introduction in future will be of less importance than in the past. Particular attention is being paid to hybridization at this stage therefore, so that the work of sorting and testing the progeny will be increasing as the work with the introduced rices decreases. The investigation of physiological problems which have a bearing on the growth and yield of rice varieties and the fuller understanding of which may lead to major improvements has now become possible and a full programme of work has been started.

INTRODUCTION AND TESTING OF RICE VARIETIES

A further 114 varieties of rice were introduced this year in time for sowing, and these were added to the observation collection. A full list of introductions under their countries of origin is given in Appendix B. Eight further swamp rices were collected in Sierra Leone and also added to the collection which, after a few older varieties had been discarded, numbered 514. Of these, 170 are grown merely for maintenance and 344 are under observation. Full records of the new introductions were made for the punched card filing system.

Now that conditions in West Africa are such that the use of artificial fertilizers has become economic, and as it seems likely that intensification of agriculture in the next ten to twenty years will create a demand for rices showing a large yield response to artificially created conditions of high fertility, it is proposed to investigate varietal difference in response to fertilizer treatment, with a view to including this factor among those examined in the improvement programme. As a start this year a standard dressing of superphosphate and sulphate of ammonia was applied to a small sub-plot of all the varieties in the collection, the growth and yield being compared with the untreated remainder of the observation plots. Considerable variation in response was shown by this unreplicated observation trial and more critical experiments will be carried out with a view to selecting parents for a full scale breeding programme.

A search was made within the main collection for possible photoperiod-insensitive varieties suitable for growing in the dry season. Fifty-five varieties were chosen and were planted in the irrigated polders after the rains had ceased. The majority of these flowered and some looked very promising but, because of late planting and of imperfect water control during this first season, no detailed records were kept and further trials will be carried out next dry season.

The upland collection of 31 varieties (one local variety was split into two types) was again maintained, but no work was carried out on any of the rices. It is intended to expand this collection considerably next year, when an improvement programme on upland rices will be initiated.

The collection at Rokupr is still a source of varieties for other countries, both inside and outside Africa. The following were despatched during the year:

To Gambia	2 samples
To Nigeria	54 samples
To Portuguese Guinea	60 samples
To Upper Volta	54 samples
To Camerouns	4 samples
To Sudan	38 samples
To India	16 samples
To Pakistan	1 sample
To Japan	11 samples
To British Honduras	36 samples
To Wales	1 sample

Promising Varieties

It is now three years since the most promising of the new introductions have been grown on long narrow plots for full observations, and many of these varieties have now been grown on all three sites at varying levels of fertility.

On these plots of about one-twelfth of an acre, three varieties this year gave yields of over 3,000 lbs. per acre. One of them, Cadung Phen R.92 (from South Viet Nam) is in its second year and has given very good yields in both years (though it has not yet been grown on the area of the lowest fertility). The other two varieties, Sokotera (from Zanzibar) and Anak Didek (from Malaya) have consistently done well at all the levels of fertility and in all the seasons and are on average the best two yielders. Bong Sen Den 2R.10 (from South Viet Nam) again did well though it did not reach the high yield of the previous year. Nachin 11 (from Malaya) once more showed its inconsistency with a lower though still good yield.

Other rices which have given good yields this year and which have been consistently good over the three years are Radin China 4, Radin Siak 34, Mayang Ebos 80 and Seri Raja (all from Malaya). Parn A-191 (from Thailand), Maung Nyo B 24-92 (from Burma) and Pai Gazo (from North Borneo), which had high yields this year, all gave indifferent yields when they were on the area of lower fertility. Gantang (from North Borneo) has behaved similarly, the yield this year when it was grown on the less fertile area being disappointing. The other rice which has previously shown up well, H.R.8 (from Hyderabad), has this year given a very indifferent yield despite being on the most fertile area. Of the newer introductions, Bambako (from Guinea) and Mas 2401 (from Java) have given reasonably good though not outstanding yields in both the years that they have been grown.

Only one of the six standard varieties which have been included in this collection, Toma 112, has averaged as good a yield as the newer varieties over the three years. The mean yield over this time of the seventeen newer rices is 2,600 lbs. per acre, an increase of 17 per cent over the mean yield of the standard varieties.

Four yield trials were laid down on mangrove land at Rokupr this year. Three years' results are now available for one trial of early maincrop rices in which Toma 112 and the early rice D99 were included as standards. In 1957, Parn A-191 had a significantly higher yield than any other variety. In 1958 and 1959 however the only significance has been that D 99 (the early variety in the trial) has had a significantly lower yield. The combined three year analysis shows Parn A-191 to have a significantly higher yield than any of the other introduced varieties,

though not of the control Toma 112. Toma 112 itself has given a significantly higher yield than Anak Didek (from Malaya), and D 99 has given a significantly lower yield than any other in the trial. Because of its uncertainty in behaviour, which has already been noted, and because of a tendency to lodging Parn A-191 is not being released at present. There has been a significant effect of seasons, 1959 giving the highest yields and 1958 the lowest. When the varietal variance is compared with interaction the only significance lies in the lower yield of D 99. It can thus be said that in no ordinary season is this early variety likely to give as good a yield on this type of mangrove soil as the early maincrop rices tested. Details of the experiment are given in Table 1.

The yield trial of late varieties established in 1958 was repeated but failed to show any significant difference in yield this year. Yields were good—in the order of 3,000 lbs. per acre.

Two other yield trials of varieties were laid down on mangrove land on the station. One tested nine early promising varieties and the other twenty-five maincrop and late maincrop rices. Both experiments were designed as balanced lattices with small plots. Significant results were obtained but there was some competition between varieties in adjacent plots and it is not proposed to report the results until further trials on similar lines have been carried out.

Five varietal yield trials were carried out on non-mangrove lands on the station extension areas. At Mando, on grasslands of medium fertility on the levee of the Little Scarcies river, above all but the highest river floods and remaining moist largely from rainfall, the trial has now reached its third year. Neither in any one year, nor in the combined analysis has any significance between yields been shown. This is mainly due to considerable soil variation, shown by a high coefficient of variation. As the newly released variety Radin China 4 has given the highest yield and the standard variety Lead has given the lowest it is considered that Radin China 4 can safely be recommended for this type of land.

TABLE 1
Yield trial of early maincrop varieties

Layout 7×7 Latin square.

Plots 12×12 feet planted at measured 6 inch spacing 2 plants per stand.

Area of plot harvested .0023 acre.

Variety	Mean yield in lbs./acre			
	1957	1958	1959	Variety mean
Parn A-191	3,351	2,952	3,783	3,361
Toma 112	2,954	3,146	3,490	3,196
Nachin 11	2,748	2,489	3,820	3,017
Siam 9	2,941	2,578	3,536	3,017
Radin Siak 34	2,770	2,722	3,475	2,987
Anak Didek	2,211	2,909	3,655	2,924
D 99	2,635	1,758	2,785	2,392
Season mean	2,801	2,651	3,506	2,985
Critical difference (5%)	342	376	494	224
Critical difference (1%)	413	506	665	298
Coefficient of variation	10.0	13.0	12.9	12.3
Critical difference Seasons (5%)				148
Critical difference Interaction (5%)				526

At Kontobe, on rather infertile grasslands on an inland riverain flood plain which floods shallowly each year in the rains and dries out thoroughly in the dry season, yield trials have been laid down under full mechanization in conjunction with the Sierra Leone Department of Agriculture for the past four years. It has not been possible to standardize the form of these trials, and this year two trials were carried out, one of early varieties and one of maincrop varieties. The latter showed no significant differences between yields, all of which were poor. In the other trial, Sokotera (from Zanzibar) and Haji Haroun (from Malaya) together with the standard Sughandi 57, all gave higher yields than the Lead standard or any of the other varieties. Details of this experiment are given in Table 2.

As the problems for rice growing on this type of land are considerable, these series of extensive variety trials are being discontinued as premature and more intensive trials will be carried out in future. No variety has consistently done well and none can confidently be recommended at present. It is of interest to note that, excluding the 1956 trial which was on a different, more fertile, site, the mean yields of the trials for 1957, 1958 and 1959 have been 492, 662 and 820 lbs. per acre—a steady increase. A dressing of 200 lbs. per acre of superphosphate has been applied to the land each year and this increase in yield is compatible with the suggestion that toxic amounts of aluminium are being immobilized as insoluble aluminium phosphate.

TABLE 2
Yield trial of early varieties—Kontobe

Layout Randomized Block 4 replications.

Plots 220 yards $\times$ 11 feet 8 inches combine drilled at 50 60 lbs. acre seed and 200 lbs./acre superphosphate.

Area of plot harvested .18 acre.

<i>Variety</i>	<i>Mean yield in lbs./acre</i>
Sokotera	1,370
Sughandi 57	1,225
Haji Haroun	1,211
Pindosein A 29-20	840
HM A9	833
H.R. 8	802
Lead	787
Faya	760
Critical difference (5%)	242
Critical difference (1%)	330
Coefficient of variation	16.8

Near Torma Bum, a trial was duplicated on two sites. One, near Makita, on less fertile land and one, near Mayeke, on more fertile. Both these sites are on reasonably good grasslands which flood shallowly for a considerable period from the Sewa river. The trial on the less fertile land suffered from considerable soil variation but even so Radin China 4, though not differing significantly in yield from the local rice Mereke which was used as a standard, had a yield significantly higher than that of two of the other introduced rices and of the floating rice Mbagboli. In the other trial a similar result was obtained, the yield of Radin China 4 not being significantly different from that of Mereke but both being higher than three other varieties. Details of these experiments are shown in Tables 3 and 4.

TABLE 3
Yield trial—Makita site

Layout Randomized Block 6 replications.
Plots 60 × 12 feet broadcast.
Area of plot harvested .017 acre.

<i>Variety</i>	<i>Mean yield in lbs./acre</i>
Radin China 4	1,606
Pai Gazo	1,276
Mereke	1,243
Anak Didek	1,089
Seri Raja	1,001
Mbagboli	803
Critical difference (5%)	465
Critical difference (1%)	633
Coefficient of variation	34

TABLE 4
Yield trial—Mayeke site

Layout Randomized Block 4 replications.
Plots 126 feet × 24 feet 4 inches broadcast.
Area of plot harvested .07 acre.

<i>Variety</i>	<i>Mean yield in lbs./acre</i>
Mereke	2,698
Anak Didek	2,418
Radin China 4	2,368
Mbagboli	2,055
Seri Raja	1,693
Pai Gazo	1,232
Critical difference (5%)	586
Critical difference (1%)	795
Coefficient of variation	19.4

Radin China 4 which was released from the station recently has confirmed its character of consistent season to season performance and wide ecological range in Sierra Leone at least. At the Nigerian Federal Rice Research Station at Badeggi however this variety, and the other variety released last year, Faya, have different durations from those they have in Sierra Leone and in trials are compared with later varieties than at Rokupr. These trials so far have not been conclusive and they are being continued. Neither Radin China 4 nor Faya therefore have yet been released by the Federal Rice Research Station within Nigeria. This underlines the importance of the physiological work on the effect of light and temperature on duration and yield which is being started. Better understanding of these factors will make it possible to make more definite recommendations over the whole of West Africa.

The fertilizer responses of five and three varieties respectively were compared in two trials, where fertilizer applications were sulphate of ammonia at 0 and 2 cwts. per acre, superphosphate at 0 and 2 cwts. per acre and hydrated lime at 0 and 2 tons per acre. In neither trial, one of which was on mangrove soil at Rokupr and one on grasslands at Mando, were there significant differences in yield, possibly due to ill chosen fertilizer levels

and too small a plot size. The trials have however given information on the technique of such types of experiment and suggest that there may be considerable difference in fertilizer response between varieties.

Milling Experiments

The promising varieties have now all been tested for milling quality. Tests have been made both on raw and on parboiled paddy, but more attention is being paid to the results from parboiled paddy as these are likely to have more practical importance in West Africa. Total milling out-turn (of whole and broken grains) of the promising varieties varied from 64 to 71 per cent. The percentage of broken grains varied considerably but, since this is dependent on other than genetic factors, less attention is being paid to it in assessing relative quality. The two varieties released last year, Radin China 4 and Faya, both had high quality. Information on quality is being added to the records of varieties and will be included on the information sheets issued when varieties are released.

The problem of breakage of grains in the milling of paddy is known to depend on the treatment of the paddy. The experiment started last year on the influence of weather conditions on the cracking of the grain has been continued and expanded. It is well known that internal cracking of the grain—erroneously known as sun-cracking—is due to a cycle of alternate wetting and drying of the grain. This cycle of alternate wetting and drying of the grain in the field is found in Sierra Leone when the harmattan wind is blowing—commonly towards the end of December or in early January when maincrop rices are ripening. At this time of the year afternoon humidities may be low while night humidities are high and heavy early morning mists and dew are common. The changes in moisture content and in cracking in a crop of ripening Radin China 4 were followed at this time of the year, and the results are shown in Table 5. Night humidities were usually nearly 100 per cent and on several occasions when the morning mist was particularly thick the rice panicles carried visible surface water. The date of harvest of this crop was determined by the usual criteria—general appearance, stage of drying of the flag leaf, condition of basal grains on the panicle, etc.

TABLE 5

Appearance of internal cracking in the grains of a ripening rice crop

<i>Days before harvest</i>	11	10	9	8	7	6	5	4	3	2	1	0
Relative humidity % at 1500 hrs	32	33	35	53	46	34	28	66	58	34	55	54
Moisture in grain % at 1400 hrs	18	—	15	17	15	11	11	12	12	12	14	14
Grains cracked %	6	6	16	24	23	31	39	34	38	46	46	45
Weight of 100 grains paddy at 13% mois- ture: grams	1.8	—	1.94	1.92	1.92	1.92	1.99	1.98	1.97	—	—	—

It can be seen from these figures that harvesting earlier than at the traditional time will give a crop with very much less cracking in the grain, and that there is little relative change in weight in the grain during the last week so that yields are not likely to be affected by an earlier harvest. In other rice producing countries, crops grown for milling purposes are usually harvested at an earlier stage than those grown for seed and it can be seen from the results of this experiment that this practice would be worth while in Sierra Leone if breakage in milling is to be reduced. In

Gambia, northern Ghana and northern Nigeria, the effect of the harmattan wind is more severe than in Sierra Leone and it is likely that similar considerations will apply there. The harmattan affects the crop both by its duration and its strength. The duration will determine the number of cycles of alternate wetting and drying the crop experiences in the field and also the proportion of the total crop that is affected, while its strength will determine the amount of cracking occurring in each drying cycle, since low moisture contents and fast drying both give rise to cracked grains.

When cracking of the grain has occurred in the field, the next problem is to determine whether post-harvest treatment can further influence the breakage during milling. Paddy from the last experiment with an average of 45 per cent cracked grains was therefore milled raw after drying in three ways: in the sun; in the shade; and artificially at a slow rate. Little difference in the amount of breakage was apparent, the recovery of whole grains being about 53 per cent (weight of paddy). The paddy was then parboiled and again dried at the three rates before milling. Recovery of whole grains had increased to an average of 67 per cent. There were some slight differences in recovery with the different drying treatments after parboiling and the significance of these will become apparent in the next experiment.

In the last experiment the paddy was milled at constant moisture content of about 12 per cent. The experiment which is now described examines the effect of methods of drying when milling is carried out at various moisture contents. This information was particularly needed for parboiled paddy. Four drying treatments were given: sun drying; shade drying; and artificial drying at two different rates. The latter were carried out on the experimental dryer and in both cases the air speed remained constant, the temperature of drying being 40° C. and 35° C. respectively. Samples of seventy grams, spread in layers approximately three grains thick, were dried to 12 per cent moisture content in two-and-a-half and three-and-a-half hours respectively. The paddy was sampled as it dried, the moisture content determined after reaching equilibrium, and milling carried out. This experiment was repeated with four varieties. In all cases the shapes of the curves comparing moisture content with breakage under each treatment were similar, the effect of the variety being merely an effect on the position of the curves. The results are best expressed graphically and Figure II shows them for Radin China 4. Only the curves for the quickest (sun drying) and the slowest (slow artificial drying) rates are shown for simplicity. Those for the other two treatments are intermediate, though the shade drying curve is rather erratic due to the difficulty of standardizing this method.

These results are of considerable interest. The curves for raw paddy follow the generally accepted thesis that as the moisture content of the grain is reduced the out-turn of whole grains improves, until a moisture content of about 11 per cent is reached, when it is then at an optimum and when further drying decreases milling quality. It is seen from the figure that with raw paddy the method of drying has only a small effect on quality, what differential effect there is decreasing as the optimum of 11 per cent moisture content is approached. When parboiled paddy is dried, the position is very different: when the paddy is dried slowly, there is less breakage than in raw paddy and amount of breakage is not affected by the moisture content of the grain. However, when parboiled paddy is sun-dried, no difference from slow drying is apparent until 14 per cent moisture is reached; below this level the breakages markedly increase with decrease in moisture content until at 10—11 per cent it is markedly greater than that of raw paddy at the same moisture content. On drying

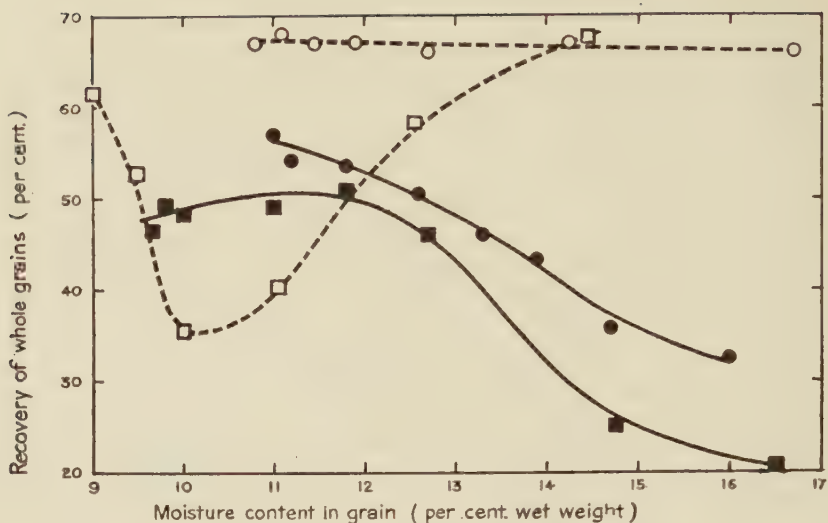


FIGURE II. The effect of drying on milling of Radin China 4. (Solid lines - raw milled; broken lines - parboiled milled; black and white squares - sun dried; black and white circles - artificially dried slowly.)

below this point there is a rapid decrease in breakage. These results, which are illustrated in the figure for one variety, have been repeated for each of the varieties tested, and would appear to define general principles which are of considerable practical importance. In Sierra Leone, at the Government Rice Mills, paddy is normally parboiled and then sun dried; milling is then carried out at about 11 to 12 per cent moisture content. Breakage is very high, and this has been thought in the past to be due to weather conditions at harvest; it now appears that it is probably due to the combination of treatments used at the mill, and that considerable improvement can be obtained by slow drying or, if this is not feasible, by milling sun dried rice at a higher moisture content. More recently, artificial driers have been installed at the mills and it will be of interest to see if these lead to any improvement in respect of breakage in milling.

Nutritional quality

In connexion with a project for the determination of the relative nutritional properties of red and white rice, a series of samples of milled rices and paddy were sent to the Tropical Products Institute at their request. They carried out standard analyses on ground samples of the whole milled grains and have submitted a report, the main points from which are summarized below. Appendix C shows the analytical results, and for comparison are included results from four samples analysed by the Tropical Products Institute for the Nigerian Federal Rice Research Station, and typical figures from the literature.

The Tropical Products Institute notes that the calcium and thiamine contents of the Sierra Leone rice samples are rather low compared with the typical average values for rice quoted from the literature. As would be expected, the milled raw rice samples are of poorer nutritional status than the corresponding milled parboiled rice samples, but it would appear that there is a smaller percentage loss of nutrients in milling raw red rice than raw white rice.

The analytical results show that the red varieties of both Sierra Leone and Nigerian rice have a higher nicotinic acid content than the white

varieties. It has been determined elsewhere that the nicotinic acid content of hulled Indian red rice is higher than that of hulled Egyptian white rice and that the bulk of the nicotinic acid is contained in the pericarp and aleurone, which in the red rice constituted 7 per cent of the whole grain as opposed to 5 per cent in the white rice. This evidence suggests that the higher nicotinic acid content observed for the red varieties of Sierra Leone and Nigerian rice is probably a general phenomenon, and may be due to a higher proportion of pericarp and aleurone rich in nicotinic acid in the grains. Nevertheless if hulled or milled parboiled rice were consumed, it would appear unlikely that this difference would have any marked nutritional significance. Both red and white varieties are nutritionally adequate from the point of view of nicotinic acid.

It can be seen from the table that there is some evidence that red varieties of rice may have a higher ash content, but it would appear that the variations in protein and thiamine contents are independent of the colour of the grain.

From the evidence of the analyses given in the table it would appear that, apart from the higher nicotinic acid content and a possibly higher mineral matter content, there is nothing to suggest that red varieties of rice are markedly superior on nutritional grounds to white varieties.

The Tropical Products Institute finally comments that the number of samples examined is too small for any conclusions to be drawn regarding the possible effects of environment on the composition of Sierra Leone rice.

Although thiamine content in general is lower than the average values from the literature, it is still adequate in the parboiled rice. The Food and Agriculture Organization of the United Nations recommends that 1.8 micrograms per gram should be the aim though, as this is a high target for much of the world, it says that 1.5 micrograms per gram is acceptable at present. Samples of commercial rice from Sierra Leone examined at the Tropical Products Institute have shown very much lower thiamine contents and it appears as if considerable loss can occur in storage, especially if the moisture content of the grain is high.

The recommended nutritional requirement of calcium is 0.143 per cent. The low calcium figure in Sierra Leone rice is however not of particular importance as it will be seen that the average value from the literature is only a tenth of the requirement. Calcium in a rice diet must in fact always come from outside sources—one of the most important of which is green vegetables.

Ten per cent protein is usually taken as the minimum nutritional level. While the proteins in rice are of a high quality and digestibility for vegetable proteins, they are in general insufficient. It is of particular interest therefore that the analyses show high protein values for the two improved rice varieties Lead and Indo-China 53. However, as the figures are few it would be a mistake to place too much emphasis on this and the Tropical Products Institute have suggested that in view of the tendency of local diets to be low in protein, it would seem advisable to clear up this point. Further trials are therefore projected in which the protein content will be considered in relation to the nitrogen status of the soils.

The comparatively minor differences in value between parboiled rice at different degrees of milling is also noticeable. The Tropical Products Institute report that these are due to diffusion of the water soluble nutrients, principally located in the pericarp and aleurone layers, into the rice grain during the parboiling process. The differences would of course be much more marked for undermilled, optimum milled and overmilled raw rice.

This work underlines the importance of encouraging the consumption of parboiled rice in West Africa. Not only, as reported earlier, will it

have better milling qualities, but its nutritional value is immensely superior. It is usually easy to introduce parboiled rice to a population who are acquiring a rice eating habit, though it is difficult to do so in a population who are already accustomed to eating raw milled rice. Properly parboiled rice is exceedingly palatable, but there is a real danger of inefficient and unsatisfactory methods of parboiling producing an unpalatable product and thus a preference for raw milled rice becoming established.

SELECTION OF IMPROVED RICES

Little work was carried out with selections this year. Observations were made on the sixty-three re-selections of Ngasein 57 and the best nine lines were retained, the remainder being discarded. The remaining selections of the other rices were merely maintained. It is hoped to make some final decisions on these in the coming year, Kema and Lath after trials in the deep water tank, Panianala and Meike after field trials at Kontobe and Mbagboli after field trials at Torma Bum.

HYBRIDIZATION

The offspring of the hybridizations made in 1951 have been put into trial for the first time this year. The results of the trials vindicate the immediate policy adopted—the considerable increase in introduction of varieties and concentration of attention upon investigation of these rices rather than on hybridization. The objectives of the 1951 hybridizations have in the main been achieved, but the more rapid survey of rices from all parts of the world has produced even better lines. The introduction phase is now almost complete and the extended hybridization programme now started, using the large pool of potential parental varieties well adapted to West African conditions now available in the collection, will become of increasing importance.

Late varieties

The remaining strains of the F_8 generation of the cross X(51)7, India pa lil 46 $\times$ Kav.12, have now been discarded as they have shown little promise.

Maincrop varieties

Hybrids in the F_8 generation were this year put into a triple lattice yield trial together with F_8 hybrids of early rices. Among the eight lines of the *indica* $\times$ *japonica* cross X(51)4, Ngasein 57 $\times$ Tai Chu 65, in this trial, none exceeded the Ngasein parent, though one line had a yield that was not significantly lower (at the 5 per cent probability level). These lines are also being tested in irrigated plots in the dry season to study their response to photoperiod, and further trials await the result of these studies. The original object of this cross was to obtain a short strawed rice with yield equal to the Ngasein parent. This has been achieved but slight spikelet sterility, which selection has not completely removed, reduces the value of these strains, as it has been shown that this effect may become worse when they are grown on a different site.

Four strains of the cross X(51)5, Toma 112 $\times$ Ngasein 57, were put into trial and again none gave a significantly higher yield than the Ngasein parent and only one was not significantly lower. This cross was designed to combine the high yield of Ngasein 57 with the strong straw of Toma 112. Here again strong strawed introductions yielding better than either parent are now on trial or released and no further work is being carried out on this cross, the four best lines being transferred to the collection.

The maincrop cross in the F_3 generation, X(56)2, Bolo 108 $\times$ Ngasein 57, was again grown in bulk and mass selections were made for sowing in the F_4 generation, when it is expected that line selection will be started.

A new programme of hybridization for maincrop rice was started this year. Twelve parents were selected from the best of the promising variety collection to include as wide a range of variation in yield components as possible. Selected crosses were made among these and more will be made in 1960. Some investigations into clonal propagation and early trials in the segregating progenies are being planned to guide the future selection methods to be used in this programme.

Early varieties

Seven of the best strains of the F_3 generation from the cross X(51)1, Yenti $\times$ DC39 15, were put into trial, and three significantly outyielded the Yenti parent. (The other parent was not available for comparison). Since better short duration types resistant to *Piricularia oryzae* have now been introduced, further work with this cross is not needed and the best lines are being transferred to the collection.

As referred to in the last report, multiple crosses were attempted in order to form a diallel series but difficulty was experienced in making sufficient crosses. The hybrid offspring from those made were grown on and bulked for each cross at harvest for sowing in the F_2 generation next year.

Very early varieties

Many years of introductions have failed to produce any swamp variety of less than about 140 days duration capable of giving a reasonable yield. Such varieties are needed for use in double or multiple cropping schemes, farming associated with dams and irrigation works, and also where the rainfall is brief or unreliable. Photoperiod sensitivity of such varieties needs to be low or absent.

Seven parental varieties were chosen on a basis of performance in the collection over several years and selected crosses were made. No very short duration types were included, since it was thought easier to select the easily recognisable progeny of high yielding parents showing transgressive segregation for earliness than to look for high yield among the progeny of poor early rices. If little or no transgression for earliness occurs in the F_2 generation, at least one very early variety will be included in a second series of crosses.

Several techniques designed to speed up the breeding programme were used. Last year it was found difficult for one person to make sufficient crosses with the usual hot flask technique, as the time during each day when this is effective is limited. This method was therefore supplemented by the clipping method whereby the lemma and palea of spikelets within a day of flowering are cut just above the anthers and the stamens removed intact in the unripe condition. This is done the evening before pollination is planned. In the morning these cut spikelets can be quickly pollinated both before and after the rather brief period during which the hot flask method is in use. A lower percentage of seeds set when this dissection method is used but since many spikelets can be prepared quite easily it is not a serious disadvantage. By using these two methods in conjunction several crosses can be made on the same day by one person. Other workers have reported that germination of these mutilated seeds has been poor or absent, and they have had to be germinated on nutrient agar. It has been found at Rokupr that treatment of clipped seed for twenty minutes with a 0.1 per cent solution of mercuric chloride preceded by a rinse in 1 per cent teepol produced a high degree of surface sterility and that seed

treated in this way germinated almost as well as intact seed. Germination was carried out on filter paper in sterile petri dishes irrigated with either boiled water or boiled nutrient solution. Both media gave equal practical results and in all cases fungus growth was almost completely absent.

In order to sow the seed after harvest without delay it was necessary to break the dormancy. The method used was that developed at Rokupr and described later in this report. This useful technique enables the seed to be germinated immediately after harvest and obviates the older method of dehusking with the concomitant tedious work of husk removal by hand and germination under sterile conditions.

It was decided to try to grow the F_1 seed from this programme in the dry season, thus saving a year and having the F_2 generation ready for sowing in the next rainy season. Six of the parental varieties were known to show greater or lesser sensitivity to photoperiod and to have delayed, irregular or inhibited flowering under the long-day conditions of the dry season. All the F_1 seed and parental varieties were therefore planted in pots and at six weeks of age were given a ten-hour-day regime by transferring them into a dark room at dusk and delaying removal until 9.00 a.m. the following morning. Flower primordia were induced within six to twenty days, and most of the plants had flowered after thirty days treatment (at ten weeks old).

Use of these last two techniques would enable three generations a year of very short duration rice to be grown and programmes designed to satisfy easily tested requirements, such as positive or negative resistance to a given disease, could be very quickly carried through. For yield breeding however it seems essential to select in the correct habitat and season and thus, except perhaps for the earliest generations, the routine work of the breeding programme will still remain largely seasonal.

Floating rices

The nine strains of the cross X(53)1, Indo-China 53 $\times$ Indo-China 24, in the F_6 generation were retained and will go into trial in 1960 on the new station extension area at Torma Bum.

Mass selection was again made in the bulked F_3 generation of the cross X(56)3, Toma 112 $\times$ Indo-China 53, and line selection will be started in 1960.

Inter-specific crosses

The F_1 generation of the crosses made between *Oryza sativa* and *O. glaberrima* were grown this season. Records were made of the characters of the hybrids, all of which showed complete pollen failure and consequent absence of seed set. Attempts were made to produce the amphidiploid of this cross using the techniques of colchicine treatment normally employed with wheat and rye, but these were unsuccessful.

A further series of cross pollinations were made between Indo-China 53 and the floating *glaberrima*, Baban Fari A. 1. Seed set was much better than in normal interspecific *sativa* $\times$ *glaberrima* crosses possibly due to the copious pollen production of the *glaberrima* parent, and over sixty seeds were set. Work is now in progress on inducing polyploidy in this material by using a modern Japanese technique whereby the coleoptile of the germinating seed is split lengthwise and 0.1 per cent colchicine solution is applied to a cotton-wool strand inserted in the cut. Seed thus treated is now being grown during the 1960 season.

PHYSIOLOGICAL WORK

It has become apparent that the factors influencing the duration and yield of rice in West Africa, notably photoperiod, light intensity and

temperature, are of considerable importance and that a proper understanding of their effect could lead, through the improvement programme, to a greatly increased rice production. Experiments in the field, those of which for last year are reported below, are indicating the type of effect that takes place, but for a complete knowledge of the effects of these factors, both singly and in conjunction, it is necessary to carry out controlled laboratory experiments. Designs have therefore been prepared for, and construction has started on, a series of growth cabinets in which temperature, and intensity and duration of light can be accurately controlled and measured. The designs allow for considerable flexibility; all combinations of factors should be possible including differential temperature treatments during light and dark periods.

Work on salt tolerance and drought resistance has been confined to investigations into high osmotic concentrations of culture media. The hydroponic apparatus is temporarily being used for an investigation into the possibility of nitrogen fixation by the rice plant. A recent report from India has suggested that such fixation of nitrogen takes place and the fundamental implications of this are so important that immediate investigation seemed desirable. The results of this work, which is still in progress, will be reported at a later date.

Factors influencing Duration and Yield

The integrating photometer has been repaired and records from it have been kept throughout the season.

The successional sowing experiment reported last year was repeated using the photo-insensitive variety and the two earlier photo-sensitive varieties and an increased range of sowing dates. Only results from the three stations of similar latitude are available and there is still insufficient information for further conclusions to be drawn at this stage.

The results of the photo-sensitive varieties were very similar to those obtained last year and the range of durations at the various stations is shown in Table 6.

TABLE 6
Range of durations in days at three stations

<i>Station</i>	<i>Lead</i>	<i>Radin China 4</i>	<i>First sowing</i>	<i>Last sowing</i>
Rokupr	231-103	255-136	15/4	2/9
Badeggi	177-154	248-164	27/4	17/8
Nyankpala	202-122	204-183	10/4	14/8

The results for the photo-insensitive variety, Tai Chu 65, show considerable variation. Once again however the durations were consistently shorter at Nyankpala than at Badeggi or Rokupr.

A further successional sowing trial was established at Rokupr this year, to investigate changes in yield and in yield components with sowing date. Seven sowings were made between May and October and the varieties Tai Chu 65, Lead and Radin China 4 were used. This experiment is to run for three years and no detailed comment will be made at this stage. A constant feature however was that in all cases yield, panicle number, panicle weight and the weight of 100 grains of paddy were low at the beginning and end of the experiment, there being either one or two maxima, though those for yield did not necessarily correspond with those for any given yield component. Another feature was the good correlation that was found between the area of the flag leaf and yield.

Two further statistical yield trials were laid down to examine the effect of sowing date on yield. One, in which the variety Lead was used, showed no significance. The other, with Radin China 4, details of which are given in Table 7, showed that the first sowing gave a significantly lower yield than the second—on 18th June, the date of sowing that gave the highest yield in both significant experiments last year—and that the last sowing gave a yield significantly lower than any other. These experiments are being continued and no further conclusions are possible at present. It seems likely however, from the rather variable yield distribution of each variety each year, and having regard to the results of the experiments on yield components, that there are a number of maxima depending on different factors and seasonal variations may throw any one of these into prominence. The more precise laboratory work planned should elucidate this.

TABLE 7

Effect of sowing date on yield—Radin China 4

Layout 6×6 Latin square.

Plots 15×15 feet planted at measured 6 inch spacing 2 plants per stand.

Area of plot harvested .0038 acre.

Sowing date	Mean yield in lbs./acre
June 18th	2,549
July 30th	2,500
July 16th	2,466
July 2nd	2,460
June 4th	2,428
August 13th	2,254
Critical difference (5%)	115
Critical difference (1%)	157
Coefficient of variation	3.9

Tolerance to Surplus Water Regimes

The first of a series of trials in the deep water tank was laid down this year. This was a preliminary trial with floating rices. Experience in Nigeria in the past has suggested that among floating rices the varieties of *Oryza glaberrima* were more vigorous and had a faster growth rate under flood conditions than those of *O. sativa*. Two floating varieties of *O. glaberrima*, Baban Fari A.1. and Dan Boto A.1., were compared with two floating *sativas*, Mbagboli and Indo China 53. B.G.79 was included as a non-floating *sativa* for comparison. Two dates of sowing were chosen so that exposure to flooding came at four and eight weeks from germination respectively, and a number of flooding regimes were applied to produce various conditions that might occur in the field—prolonged gradual flooding, gradual flooding followed by a decline in water level and gradual flooding followed by sudden deep flooding. All the varieties were grown in pots under similar conditions and transferred to the tank at the appropriate age.

Little distinction was found possible between the various methods of flooding, but the stage of development when flooding occurred proved to be a most important factor in survival. Of the 8-week old plants, only four out of 180 failed to survive, these four all being of B.G.79 under the most severe flooding—four feet submergence. Less than a half of the 4-week old plants survived identical treatment. (See Table 8). Comparison of the number of survivors of each variety suggests that the range of vigour

within a species is as great as that between species when tolerance to flooding is considered.

The height of the plants used in the second part of the experiment was measured at 7 weeks, and again after 40 days flooding, when tiller numbers were also counted. Results are shown in Table 8. It is seen that there seems to be a general relationship between seedling vigour and final plant height and also that the *sativa* varieties have shown markedly better tillering than the *glaberrima* varieties.

These general indications from the first season's experiments will be followed up in 1960, when observations made in the tank can be checked with those made in the field on the new station extension at Torma Bum. More detailed investigations into the effect of stage of development at flooding on growth and survival will be carried out.

TABLE 8
Comparison of sativa and glaberrima rices under flooding

	<i>sativa</i>			<i>glaberrima</i>	
	<i>B.G.79</i>	<i>I.C.53</i>	<i>Mbagboli</i>	<i>B.F.A.1</i>	<i>D.B.A.1</i>
<i>Submerged at 4 weeks</i>					
Survivors out of 36	11	13	18	9	15
<i>Submerged at 8 weeks</i>					
Survivors out of 36	32	36	36	36	36
Mean height in cms.					
at 7 weeks old	26.1	27.8	31.4	29.1	29
at 14 weeks old	108	135	151	134	139
Mean tiller number					
at 14 weeks old	2.05	1.53	1.50	1.17	1.28

Dormancy and Viability of Rice Seed

Preliminary experiments on dormancy in rice seed were first mentioned in the Annual Report for 1956, when it was pointed out that, in order to speed up the breeding programme, it would probably be useful in certain cases involving very short duration lines to grow two successive generations in one year. Most of the very short duration rices which have so far been grown at Rokupr have a duration of not less than about 140 days. When it is considered that the average period for maximum germination to be obtained after harvest is normally twelve weeks for varieties grown at Rokupr, it becomes obvious that some artificial method of shortening the dormancy period is necessary. It would undoubtedly be possible to breed for a short dormancy period, but this would be a disadvantage in a variety as pronounced dormancy prevents sprouting under wet conditions at harvest time. A simple practical method was required therefore by which the dormancy period could be reduced during the breeding programme but remain unaltered in the variety finally released to the farmer. As has already been mentioned earlier in this report, a suitable method has been developed and this, in conjunction with the growing of plants under artificially shortened days, is now in use for the growing of two or more successive generations in the year. This method was based on information obtained from fundamental studies on dormancy and a description of it is given after a general discussion of these studies.

The distribution of the dormancy periods (i.e. time taken from harvest until the seed will germinate under suitable conditions) between individual seeds has been examined in a large number of varieties. The mean dormancy period has been defined as the mean of the dormancy periods of the individual seeds in a population. The evidence shows that this

distribution is a normal one in a pure variety. Since germination usually reaches 100 per cent and a normal distribution is symmetrical, a good estimate of the mean dormancy period can be obtained by observing the time taken from harvest until 50 per cent germination is achieved as determined by a series of germination tests. The main error involved is due to the fact that there is no obvious way of deciding when grain is ripe for harvest to within a few days. Harvesting the seed prematurely tends to speed up the processes leading to loss of dormancy, whereas late harvesting has little effect on the date on which the mean dormancy period is reached. It follows that, when estimating the mean dormancy period, the error is much smaller if harvesting is too early rather than too late.

If a single value is to be used to describe the dormancy period of a variety, there is much to be said in favour of using the mean dormancy period. However it is realized that, from the practical point of view, this measure may not be sufficient on its own; only 50 per cent germination will occur at the end of this period and, in breeding and agricultural work, a higher percentage germination than this is needed. The method of direct observation is particularly inaccurate when a high value for percentage germination is required because of the nature of a normal distribution: the values which can be determined with least accuracy are those which approach 0 and 100 per cent germination as they depend on the behaviour of only a small proportion of seeds in the sample. A more accurate method is to calculate the parameters of the ideal curve from a number of observations and to predict the desired level of germination from this. A convenient and rapid method based on this principle which has been used on the station is as follows: the results of a series of germination tests are plotted against time using a probability scale for the germination percentages; a straight line is drawn through these points in the middle ranges of the distribution and the time of any given high level of germination may be predicted by extrapolation of this line.

No correlation has been detected between duration (period from sowing to modal flowering plus 30 days) and mean dormancy period. This is contrary to previous Indian reports and may possibly be due in part to the fact that no extremely short duration varieties (80 to 120 days duration) were used in the analysis, as such varieties cannot successfully be grown at Rokupr. However this does not alter the fact that no correlation was apparent for varieties having greater durations than this.

In some varieties at least, there is evidence that during the process of breaking dormancy seeds go through a stage when they are capable of germinating in the light but not in the dark.

Most of the dormancy in rice can be accounted for by the inhibitory influence of the husk, and most of the residual dormancy after dehusking can be attributed to the inhibitory influence of the pericarp. Although most of the dormancy can be removed from seeds by dehusking, this is not an ideal method, as considerable care has to be taken in removing the husk if damage to the embryo is to be avoided and the dehusked grain is usually subject to severe fungal and bacterial attacks when set to germinate whereas the intact seed is not. It has been shown that the rate of water absorption is the same in dormant and non-dormant seeds and that dormant seeds are capable of absorbing sufficient water for germination. The husk therefore does not cause dormancy by preventing the entry of water—one of the early suggestions put forward to explain dormancy in some temperate cereals and a view still held by some workers with rice. The results of extraction experiments and of surgical experiments, in which small portions of the husk at various sites were removed, suggest that dormancy is not due to an inhibitor present in the husk. The results also suggest that the husk does not act as a barrier to the outward diffusion

of an inhibitor from the embryo or endosperm. However, as it has been shown that the storage of seed in oxygen markedly accelerates the breaking of dormancy—in some cases the mean dormancy period being shortened by about a half—it is tentatively suggested that the husk acts as a barrier to the inward diffusion of oxygen which is necessary for the embryo to break dormancy. The effects of storage in nitrogen and in carbon dioxide have also been investigated and these gases appear to have little effect except in so far as they exclude oxygen.

It has been shown that there is a clear negative linear relationship between storage temperature and the log. of the mean dormancy period over the temperature range 27-47° C. Thus the relationship may be expressed by the equation: $\log d = K - C_d t$, where d = mean dormancy period, t = temperature and K_d and C_d are constants. In the variety Toma 112, for d in days and t in degrees Centigrade, the constants have been determined as follows when germination tests are carried out in the dark: $K_d = 2.896$ and $C_d = 0.046$. How these constants vary between varieties remains to be investigated. Although the only temperatures investigated are within the range 27-47° C., there is no reason to suspect that the relationship described by the above equation does not hold for a wider range of temperatures. Practical upper limits for temperature however are set by the factors affecting viability which were described in the last Annual Report.

At higher temperatures, the relationship between temperature and dormancy period is little affected by moisture content over a wide range (in terms of normal moisture values for stored grain)—i.e., at least from 12 to 18 per cent—though at 27° C. (and probably also at lower temperatures) the higher moisture contents were found to delay slightly the breaking of dormancy. As these experiments were carried out in sealed ampoules, this effect of moisture content should, however, be interpreted with caution: it is probable that the oxygen concentrations surrounding the seeds at the higher moisture contents were reduced more quickly than at the lower moisture contents because of the greater respiration of associated micro-organisms at high relative humidities; thus the slight delay observed in the breaking of dormancy may not have been due directly to high moisture content.

At a still higher level of moisture content, i.e., near a value of 30 per cent which is achieved by soaking the seeds in water, a stimulation towards breaking dormancy can occur. With intact seeds this stimulation is usually small or non-existent at laboratory temperatures (mean of about 27° C.) but increases at very low temperatures (3° C.). This contrasts with the marked delay in breaking of dormancy when seed is stored dry at this low temperature (the relationship with dry seed probably being that described by the equation given previously). With dehusked seed the residual dormancy of a proportion of the seeds can be broken by pre-soaking at laboratory temperature but, unlike intact seed, low temperatures do not appear to increase the effect of pre-soaking, rather do they slightly decrease it.

The effect of temperature on wet seed has also been investigated with seed which has been set to germinate. Maximum germination of a partially dormant population of seed is achieved at an optimum temperature which is near or somewhat below 27° C. In the sample tested, no germination occurred at 42° C., although in populations which have completely broken dormancy full germination will occur at this temperature. Non-dormant populations of rice seed can germinate at very low oxygen tensions or probably even in the absence of oxygen, but the germination of a partially dormant sample is reduced, under these circumstances. When oxygen is very scarce or absent, the effect of temperature during

the germination test is reversed at the higher temperatures, e.g., there is then less germination at 27° C. for instance than at 37° C.

The discussion so far might be described as being concerned with the physical factors which affect dormancy. Concurrently with these investigations other experiments were carried out to test the effects of a wide range of biologically active substances on dormancy. Substances tested were thiourea, dl-alanine, dextrose, ethylene, thiamine, nicotinic acid, pyridoxine hydrochloride, gibberellic acid, β -indolylacetic acid, 2-naphthoxyacetic acid, α -(1-naphthylmethylsulphide)-propionic acid, 2, 3, 5-tri-iodobenzoic acid, 1-naphthoxyacetic acid by itself and in combination with gibberellic acid, naphthalene-1-acetic acid by itself and in combination with gibberellic acid, potassium chloride, sodium chloride, potassium nitrate, sodium nitrate and complete inorganic nutrient medium. The only substances which were shown to have a stimulatory effect on the germination of dormant rice seeds were gibberellic acid, nitrate ions and possibly potassium ions but it should be mentioned that the complete nutrient medium also stimulated the breaking of dormancy and that this stimulation was greater than could be accounted for by its content of nitrate and potassium ions. Although the stimulation caused by these substances is significant it is not large. Therefore, although these findings are of theoretical interest, these substances cannot be considered to have practical value as a method of shortening dormancy period.

From the work described above, the following simple practical method has been developed for rapidly breaking dormancy of intact seeds. The seeds are sun-dried to 11 per cent moisture content or less and then placed in open shallow containers in a reliable incubator at 47° C. Seven days of this treatment will remove the dormancy of all seeds in most varieties and, providing the moisture content is not greater than 11 per cent, there is no danger of loss of viability during the treatment. Considerably shorter periods of incubation will suffice with some varieties, but shorter periods can only be used with the certainty of obtaining maximum germination if information concerning the dormant behaviour of a particular variety is already available. The use of shallow open containers to hold the seeds in the incubators is a safety measure in case the seed has been put in the incubator at too high a moisture content. If the seed is too moist, this method will allow rapid drying in the incubator so that the danger of loss of viability is minimized. After incubation, the seeds are set to germinate at ambient temperature.

Experiments on viability of rice seed continue and will be reported at a later date.

DISEASES

Attack by *Piricularia oryzae* on seedlings in the nurseries was particularly severe this year—one of the worst attacks on record. Most varieties in the collection were attacked to some extent. Close records continue to be kept and two peaks of infection were again apparent. No connexion between the severity of the attack and the meteorological records can be seen, the weather over the nursery period being quite normal.

There was a small amount of attack by *Helminthosporium oryzae* in the nurseries, but *Ephelis pallida* was not seen in the field this year.

SOIL SCIENCE

Work on the chemistry and microbiology of tidal mangrove soils has continued but it has also been possible during the year to expand investigations of other types of rice soils. These latter investigations have taken the form of a number of field experiments in different localities and a series

of experiments with rice grown in buckets. These trials are linked with basic laboratory investigations into the chemistry of waterlogged soils with particular attention to their oxidation-reduction systems, which is a continuation of work started at Rothamsted and now published, and to which reference is made in the publications section of this report. It is anticipated that such fundamental studies, and their associated field trials, will lead to information of considerable practical importance in rice growing in general—not only in West Africa.

INVESTIGATIONS INTO TIDAL MANGROVE SOILS

The background to this work, which is designed to provide the basic information on which reclamation of large areas of mangrove land for rice growing can be attempted, has been fully discussed in earlier reports. Investigations during the year have been in continuation of those reported previously and have comprised further studies of the oxidation mechanisms in such soils, which are mainly bacteriological, and of their fertility status, in particular the decomposition of organic matter. With the opening of a station extension area on virgin mangrove land at Wellington, it has become possible to translate laboratory experiments into the field and practical trials of reclamation procedures are now being started.

Oxidation mechanisms

Work has continued on the mechanisms by which sulphur compounds are oxidized in saline tidal soils. The main source of acid in such soils, the oxidation of elemental sulphur by the bacterium *Thiobacillus thiooxidans*, has been reported previously. Although the oxidation of about 6 milligrams of sulphur per gram of soil (on an oven-dry basis) is sufficient for the development of a soil pH value of 2·8—2·5 the soil sulphur content is usually much larger than this and may be made up of a large polysulphide fraction. Previous experiments on the effects of lime on oxidation of sulphur compounds in these soils suggested that the polysulphide fraction was stable at normal soil pH values although it could be rapidly oxidized when the soil pH value had fallen below 3·0. More precise experiments, in which the rates of oxygen uptake by mangrove soils during oxidation have been measured and related to the oxidation of the various sulphur fractions present, have confirmed previous observations and have shown conclusively that elemental sulphur is the main constituent of the soil sulphur fraction involved in acid-formation above pH 2·5. The experiments continue and it is hoped that it will be possible to postulate exact mechanisms for the oxidation of soil polysulphides and to assess the importance of their role at a later stage.

Extremely acid polder soils may have a pH value as low as 2·0 or even lower. This extreme acidity is due to secondary oxidations which result in the presence of large quantities of soluble ferric iron. The release of soluble iron which occurs below pH 3·0 may be the result of the oxidation of otherwise insoluble polysulphides and recent experiments indicate that, although these substances may not be directly involved in acid-formation in the same way as elemental sulphur, they may make an indirect but important contribution once the soil pH value has fallen below the limiting value for their oxidation. Experiments carried out during the year have been aimed at obtaining a complete picture of the relationships between sulphur and iron oxidation and the contribution which each makes to soil acidity through the oxidation of the various sulphur compounds present. Detailed results will be published at a later stage.

The object of the investigations into the mechanisms of iron and sulphur oxidation has been to obtain information on the best way of dealing with high sulphur soils during the period of reclamation. So far, the apparent

stability of polysulphides at soil pH values above 3.0, and their possible involvement in the increase in soil acidity which occurs after the cessation of the activity of the sulphur-oxidizing bacteria just below this pH value, suggests that efforts should be made to keep up the pH value of the soil during reclamation in order to prevent oxidation and concomitant release of large concentrations of ferrous iron. Lime could be used to achieve this and would at the same time ensure the complete oxidation of the elemental sulphur present by the *Thiobacilli*, as previously reported. However, such a method depends on the soil having a content of elemental sulphur preferably less than 0.5 per cent or it would be prohibitively expensive. Periodic studies have been carried out on the soils of the station's new experimental empoldering scheme at Wellington in order to obtain estimates of the rate at which polysulphides are formed and to discover conditions which favour their formation. These experiments are still going on, but indications are that the soils initially contain a large proportion of polysulphide sulphur, particularly at lower levels, and the behaviour of the soils in the laboratory conforms to the pattern anticipated from the experiments done on soils from Rokupr. Using Wellington soils, investigations have been started to evolve a rapid method for determining the relative proportions of elemental and polysulphide sulphur present.

Experiments on Reclamation Procedures

Even given a favourable balance of soil sulphur compounds in the initial stages of the reclamation, it seems likely that a certain amount of acid-formation would be unavoidable. It thus remains to investigate the most economical means of eliminating the high concentrations of hydrogen, aluminium and manganese ions present in the acid soil. Unless the concentrations of these ions are very small, the initial use of lime or other chemical additive as part of the reclamation procedure could be prohibitively expensive. Leaching with rain water has previously been shown to be effective. It is however an extremely slow process and, in the absence of measures designed to eliminate residual toxicities, experience in Sierra Leone has shown that it may take ten years to reach completion.

A series of experiments has been carried out during the year to investigate the effect of leaching on the removal of toxic and acid substances from soil of low pH value. The general plan of these experiments was to leach samples of soil daily with standard volumes of fresh water or saline water of approximately the same composition as sea water. The percolates from the leached soils were titrated with standard alkali and the concentrations of ferrous, ferric, aluminium and manganous ions inferred from the size of the inflexions on the titration curves. Estimates could thus be made of the rates at which these ions were being removed from the soil and of the total amount of titrateable acid which was removed. The results of these experiments showed that the acid soils leached with both fresh water and saline water initially released acid substances at a very high rate and lost half of their total titrateable acidity after leaching with five times their weight of water, the rates of leaching being similar for sea water and fresh water. After leaching a soil of pH 2.6 with fifteen times its weight of water, its lime requirement (to pH 5.2) was reduced from sixteen tons to three tons Calcium carbonate per acre six inches. Given suitable drainage conditions, such a leaching could be applied in a matter of weeks using sea water; about one year's rainfall would be necessary. The results of the experiments are thus encouraging, though they must be viewed with caution until the results from tests in the field are available. Sea water is no less efficient than fresh water in removing acid and toxic substances and is readily available, as a characteristic of the soils under consideration is that they lie in the littoral zone and can

be inundated twice daily. In addition it is a cheap source of cations with which acid compounds on the exchange complex can be replaced. It has not however been possible to show that sea water is *better* than fresh water probably on account of the complicating effect of iron-oxidation which seems to occur more readily in saline leachates than in fresh water ones, and before the investigation can be put on a firm quantitative basis it will be necessary to know more about iron-oxidation at low pH values. A possible disadvantage of sea water as a leaching agent could be its sulphate content, which might enable sulphate reduction and further accumulation of insoluble sulphur compounds to occur during reclamation. The experiments have shown that this can occur, in spite of the low soil pH values, if drainage is impeded, though under tidal conditions with good drainage it might not be a serious problem. The possibility of reduced soil permeability, due to the deflocculation of clay by sodium and magnesium ions, would have to be faced when the sea water was eventually itself washed out, but there is no reason to suspect that this problem would be any more serious than in the beginning, or on the Scarcies rice lands where salt is leached from tidal mangrove land every year before rice is transplanted. In any case liming to eliminate residual toxicity would automatically improve permeability.

Young rice seedlings have been grown from seed in leached soils to determine whether they have become less toxic. Symptoms of residual toxicity, which occurred in some degree in all the soils tested, were mainly manifested in inhibition of root growth, either complete, or in less severe cases limited to the lateral roots which developed only as peg like out-growths along the main root. These symptoms coincide with those found by other workers to be correlated with aluminium toxicity in legumes. Tests carried out in the present series of experiments showed that both aluminium and manganese inhibited root growth of rice seedlings completely, though aluminium was more active, causing complete inhibition at 0.01 molar and inhibition of lateral root development at 0.001 molar concentrations. It seems likely that residual aluminium toxicity will be the more important, though high concentrations of manganese were shown in the leachates from the inflexions in the titration curves.

The investigation into leaching is being continued and it is hoped to carry out field experiments during the dry season of 1961. If preliminary leaching proves as successful in the field as it has done in the laboratory, then the problem resolves itself into the elimination of residual toxicities, and the amount of liming or other corrective material required will then have to be determined in the field. Rates of application should be small and economic compared with those which would have to be used to neutralize the whole of the acid formed.

Thus, to sum up, the method of reclaiming the soils is likely to occur in the following stages:

- (i) manipulation of soil conditions to obtain the most advantageous balance between the oxidizable sulphur compounds;
- (ii) controlled oxidation of the labile compounds;
- (iii) leaching with salt or fresh water to remove the majority of the acid compounds;
- (iv) use of chemical amendments to eliminate residual toxicity and restore permeability.

Research continues on the detailed aspects of each stage.

Decomposition of Organic Matter

Although a considerable amount of research has been made into the mechanisms involved in the production of acid conditions when a fibrous mud is dried, the relationship between the low pH values obtained and

the fibrous nature of the mud has not hitherto been elucidated. Furthermore, in the past it has been tacitly assumed that the fibrous material found in the mud of some swamps is due to the roots of *Rhizophora*, although there have been occasions when this has been doubted. That the muds found in *Rhizophora* swamps are different in composition, fertility and behaviour from those in *Avicennia* swamps has not yet been satisfactorily explained. An investigation was made therefore to examine in more detail the differences between the muds and to find the relationships if any between *Rhizophora* mangrove, the fibrous matter in the mud, and the proneness of the fibrous mud to become acid on drying.

The experiments confirmed that the fibrous material found in particular mangrove swamps of Sierra Leone is almost certainly due to an accumulation of partially decomposed rootlets of the *Rhizophora* mangrove. Analytical results showed a very great similarity in composition of the two materials and respirometric experiments showed that they have a very similar decomposition pattern. Furthermore they behave in very much the same manner when incubated aerobically, anaerobically or under waterlogged conditions.

The roots and pneumatophores of *Avicennia* decompose far more quickly than do the roots of *Rhizophora* and disappear in a relatively short time. Under *Rhizophora*, even when the thick fleshy roots have decomposed, there remain the fibrous rootlets which are extremely resistant to microbial attack—particularly under the waterlogged conditions of the swamp. In view of the extremely high carbon-nitrogen ratio (67 : 1) of these rootlets which helps to maintain the carbon-nitrogen ratio of the fibrous mud at a high value (36 : 1), considerable amounts of inorganic nitrogen would have to be added in order to promote their decomposition.

Avicennia normally occurs on land less waterlogged than that supporting *Rhizophora* and thus organic debris is less likely to accumulate, but the most important factor contributing to the fibrous nature of the mud under *Rhizophora* is the existence of the small rootlets of that mangrove. The nature of the muds in a coastal mangrove swamp has thus been shown to depend very largely upon the kind of mangrove they support although certain basic differences, such as elevation and drainage, must originally decide which type of mangrove will become predominant. Once the mangrove vegetation is established the future constitution of the underlying mud will be governed largely by the root system of that mangrove.

The main differences between the two kinds of mud in virgin mangrove swamps have been found to be as follows. The fibrous muds have higher pH values, higher contents of oxidizable sulphur, nitrogen and phosphorus, higher carbon-nitrogen ratios and larger water-holding capacities. The muds also behave in different ways when incubated under various conditions and the analytical results of these incubations help to explain why ex-*Rhizophora* muds are considered as being more fertile than muds under *Avicennia*.

The greatest difference between the muds however is in their behaviour when dried. It is therefore also the most important difference, as reclamation of mangrove swamps will, amongst other things, involve the drying of the muds. The most striking change when the muds are dried as previous work on this station has repeatedly shown is the production of strongly acid conditions in the fibrous mud whereas the reaction of the non-fibrous mud remains unchanged. In the laboratory experiments as the fibrous mud became drier its pH value steadily dropped, with a sudden decrease when 40—30 per cent moisture content was reached. If for any reason the moisture content of the fibrous mud remained between 40 per cent and 10 per cent for any length of time then more intense acid conditions resulted. In the field this would almost certainly

happen as a long time would be needed to dry the swamp mud down to 10 per cent moisture and an occasional late shower of rain could easily occur. Thus one can expect, as has been shown in practice, that the pH value of empoldered fibrous muds would drop below 4.0 as the dry season progresses. At this stage the acidity, due to sulphur oxidation, would be associated with liberated aluminium and ferric ions, and their previously bound phosphate would thus be in a soluble form. Both types of mud would also contain more ammonium-nitrogen, particularly towards the end of the dry season, especially the non-fibrous mud, probably because it would be less acid. Experiments have shown that, if lime is added to the fibrous mud before drying, then a big increase in its ammonium-nitrogen is found. Such mud had 736 parts per million of ammonium-nitrogen as opposed to 15 parts per million in fresh mud and 18 p.p.m. in dried mud. The increase would not be so large if the lime was added after the pH had fallen.

Another important difference between the two kinds of mud is the rate at which organic matter is oxidized when the dried muds are re-wetted. The muds in mangrove swamps have been wet and periodically submerged for many years and the introduction of a regular wet-dry season—as will occur on empoldering—can be expected to have considerable effects upon the rate and mode of humus decomposition.

The decomposition of humus in the muds of *Rhizophora* and *Avicennia* swamps as affected by drying was therefore examined. The additional effects of liming and fertilizing the muds were also considered. Re-wetting of the dry soil initiated a flush of decomposition with liberation of inorganic nitrogen. The intense acidity of the fibrous mud at this stage, however, prevented the nitrogen mineralization being as high as if the mud had been previously limed. In fact most of the increase in oxygen uptake was due to carbon and sulphur oxidation. If the mud was fertilized with phosphate the pH was maintained at a higher level, probably due to immobilization of aluminium ions, and thus nitrogen mineralization was increased.

These results show that the highest rate of decomposition of humus would occur during the early rains following a dry period during which the swamp had been empoldered. As the rainy season progresses the rates of humus decomposition will fall off again until a steady, slow rate is reached. Some leaching may take place and anaerobic conditions begin to appear. The changes expected to occur in the muds at this stage were investigated by incubation techniques in the laboratory. It was found that the pH status of the muds rose, partly due to loss of soluble sulphates with leaching and partly due to reducing conditions taking effect when the muds were waterlogged. The pH of the fibrous material fell a little due to anaerobic formation of organic acids when the mud was incubated in nitrogen but these decomposed further in time. Some sulphate was reduced to sulphide but it was possible to prevent this by the addition of nitrate which acted as a preferential hydrogen acceptor. It may therefore be possible to prevent the formation of insoluble sulphide by using nitrates and thus continue the removal of sulphate by leaching.

It was concluded that, if the decomposition of the fibrous material is required, it should be treated with phosphate, lime and inorganic nitrogen before drying. The inorganic nitrogen would lower the carbon-nitrogen ratio and it is emphasized that lime is essential for the decomposition to proceed. It should be noted that as rice is usually transplanted some time after the commencement of the rains, the plants will lose the benefit of the inorganic nitrogen released by the drying effect. If it is desired to utilize this nitrogen flush at the beginning of the rains, some system of premature transplanting with temporary irrigation might be considered.

A very interesting discovery during the course of this work was that whereas inorganic nitrogen added to the fibrous mud is immobilized (owing to the high carbon-nitrogen ratio), that released in the mud by drying is apparently not immobilized. Thus the fate of nitrogen added to or released in fibrous muds is receiving further attention.

For the successful cultivation of rice, toxic substances found in empoldered mangrove swamps will have to be removed largely by leaching. A laboratory investigation was thus made to find the effects upon humus decomposition of leaching mangrove muds with rain-water. The effects can be divided into two main categories, that of leaching fresh, water-logged muds and that of leaching empoldered, dried muds. The pH values were slightly raised by leaching, but this also induced increased sulphur oxidation and the fibrous mud became more acid than before if for any reason the leaching process ceased. An important practical point is that unless the muds were limed their physical structure was deteriorated by leaching. A loss of inorganic nitrogen and phosphorus occurred and, owing to the removal of salts, the rate of humus decomposition increased.

The leaching experiments have shown that maximum oxidation of humus would be obtained by leaching out the salts from the mud before it is permitted to dry. It may well be that, in practice, leaching will take place before drying and thus the humus would be conserved during the time the land is lying fallow. During the next dry season salt-free muds would be dried, leading to an enhanced flush of decomposition with the onset of the next rains.

It has not been forgotten that leaching, or drying and leaching, the mangrove muds may produce effects other than yet considered. For example, leaching such large quantities of sulphate might lead to a trace element deficiency such as that of copper, zinc or manganese.

INVESTIGATIONS INTO THE CHEMISTRY AND FERTILITY OF RICE SOILS

Preliminary work on these investigations was carried out at Rothamsted but, since the present work is a continuation and development of hypotheses then postulated, it is necessary to mention it briefly, prior to the stage when it was transferred to Rokupr.

Additions of organic matter were made to an iron-rich English soil and the resulting samples were kept in a submerged state in an atmosphere of nitrogen. The behaviour in time of the acidity (pH) and the oxidation-reduction potential (Eh) of these samples was examined. The results indicated that when a well poised oxidation-reduction system was established in a submerged soil it could be attributed to the solution and reduction of solid iron oxides and hydroxides previously present in the soil. On the basis of the assumption that the Eh of the soil solution is poised by such a simple ferro-ferric oxidation-reduction system it has been possible to derive an equation for the straight line relationship between the Eh and pH values of a submerged soil. The term governing the change of Eh with pH is three times greater than that which has been previously used when adjusting soil Eh measurements for pH change. It is thus recommended that both Eh and pH measurements should invariably be quoted as measured and a third term included for adjusted Eh. This equation also suggests the importance of pH differences across soil horizons when the solution, movement and precipitation of iron in aerated soils is considered.

Five Sierra Leone rice soils with differing organic matter and iron contents were then examined. Assuming that the presence of both ferrous and ferric iron is necessary to establish healthy reducing conditions for rice, an attempt has been made to define the empirical terms "oxidizing

conditions", "healthy reducing conditions" and "extreme reducing conditions", as applied to paddy soils. It is anticipated that this approach will be useful in the initial testing of soils for their suitability for rice growing. From the practical point of view the results suggest that healthy reducing conditions accompanied by increased availability of nutrients and protection from highly reduced substances such as hydrogen sulphide are to be found in the Eh range in which ferric iron is precipitating from ferrous in the soil solution. The ferro-ferric system thus poises the state of reduction of a paddy soil in a range which is neither too oxidizing nor too reducing, and, given a sufficiency of organic matter to bring the Eh down into the range poised by the ferro-ferric system, a soil high in available iron is very likely to be suitable for paddy providing a suitable water regime can be imposed. This hypothesis has been tested by means of a number of experiments in the field and in buckets.

This year, in the laboratory, five different extraction techniques for soil iron were tested. None proved entirely satisfactory but the evidence which was obtained of increase in extractable iron with time after water-logging fitted the hypothesis mentioned above. It has been found that a reliable indication of the state of reduction of the soil solution is given by that of the ferro-ferric oxidation-reduction system. This is best determined by a suitable extraction method. The Bremner and Shaw method for determining available nitrogen was tested on waterlogged soil samples. The determinations of ammonium in known solutions were consistently accurate but nitrate values tended to be low, though of the same precision as the ammonium values. The method promises to be very useful in assessing the fertility of rice soils with respect to available nitrogen.

Two experiments were carried out in which rice plants were grown in buckets. The first of these was designed to test the suitability of such trials in giving preliminary information about soils and the replication necessary, and was based on the Webb subtractive technique, using a soil of known low fertility from the station extension area at Kontobe. Two-and-a-half gallon polythene buckets without drainage were used and three rice plants were grown to maturity in each. After six weeks growth each of the four replicates received one further treatment designed to test the hypothesis previously developed.

The second experiment was in the nature of a preliminary trial to examine the practicability of obtaining relevant measurement of the oxidation-reduction potential of a soil in buckets and to examine the effect of extreme ranges of water conditions on rice yields and on the nitrogen levels of the soil, as well as to afford further test of the hypothesis. Rice plants were grown in buckets of mangrove soil with a high content of iron and organic matter. Various levels of soil moisture content were maintained.

Three field trials were also laid down in furtherance of this work. Iron rich soil, superphosphate, lime and organic matter (fresh vegetable material) were applied in the treatments. Lime and superphosphate were included partly to compare the effect of iron plus organic matter with lime as a means of reducing soil acidity, partly in case the added iron should immobilize phosphorus in the soil and partly to compare with other field experiments. These trials were sited on marginal land at Rokupr, at Kontobe on soil deficient in iron and organic matter and which has shown response to phosphate and lime, and on fertile land deeply flooding with fresh water at Torma Bum. The last trial gave no significant results.

A further series of field trials were laid down on marginal land at Rokupr, and on the station extension areas at Mando, Kontobe and Torma Bum. These experiments compared three levels of lime and four

levels of superphosphate application, and were carried out because existing information indicated that responses to these fertilizers were likely to be found in soils of high iron content and low pH value. The experiment at Torma Bum gave no significant result, largely due to imprecision in recording the yields.

Two further trials were laid down on mangrove soil at Rokupr. One of these compared the effects of five levels of sulphate of ammonia both in the presence and absence of a superphosphate dressing and the other the application of sulphate of ammonia at and below surface level. No significant differences in yield were demonstrated.

These preliminary trials have given information on which an extended series of trials will be based. So far the results in general are compatible with the hypothesis, but future work will be needed for complete understanding of the behaviour of the types of soil examined under varying fertilizer treatment, and for the construction of response curves to give information on the economic aspect. It is thus not proposed to comment in detail on the results from this first year's series of trials, but, as a number of points of interest are apparent from the yield figures, summaries of those where significant differences were shown are given in Appendix D. The correlation of these and future field trials on specific soils with laboratory work is expected to lead to a better understanding of the fertility of rice soils in general and a consequent wider application of the results in due course.

ANCILLARY INVESTIGATIONS

Rain Water Analyses

Last year it was reported that analysis of the rain falling at Rokupr had shown a surprisingly high content of nitrogen. This year, therefore, with the assistance of the Sierra Leone Department of Agriculture, rain has been collected for analysis from other parts of the country. Representative samples were taken of the early (January to July), mid (August to September) and late (October to December) rains, except at Rokupr where daily collection of rain was made. All samples were subsequently analysed for ammonium and nitrate content.

The overall nitrogen content of the rain (except at Rokupr) conformed with values obtained in other countries and the comparatively heavy Sierra Leone rainfall does not involve a concomitant excess of nitrogen. Although insufficient samples were available for any definite conclusions to be formed, there appears to be a correlation between the amounts of nitrogen brought down over the year and the physical features of the country. Assuming truly representative samples, the rains brought down about 3 lbs. per acre of nitrogen in the highlands to the north-east of the country 8 lbs. per acre in the middle belt of lower altitude and 4 to 5 lbs. per acre on the coast. The bulk of the nitrogen was brought down in the early rains except in the middle belt, where the nitrogen content of the rain was constant throughout the year. It could be expected that, as the rains continue, the nitrogen content would decrease due to the washing of the atmosphere, and the constant content of nitrogen in the middle belt is an unusual feature. Generally speaking the highest nitrogen content was associated with the early thunderstorms; it is interesting that the late storms had little or no effect upon nitrogen deposition.

At Rokupr however, the amount of nitrogen brought down in the early rains was, as in 1958, outstandingly high, over 20 lbs. per acre being deposited. The mid rains brought down a further 6 lbs. per acre, but the

late rains only 2 lbs. per acre. Most of the nitrogen in the early rains was, as elsewhere, associated with the occurrence of electric storms.

It should be emphasized that, whereas the rain at Rokupr was collected daily, it was collected during only three short periods in other parts of the country. It may well be therefore that the samples analysed from these latter collections did not include rain falling during particularly heavy storms and were thus not truly representative, leading to unduly low assumption of nitrogen deposition for the year.

APPENDIX A METEOROLOGICAL RECORDS ROKUPR—1959

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Rainfall (25 year average)	1.77 (0.19)	0.00 (0.05)	2.06 (0.54)	0.01 (2.33)	10.81 (7.06)	15.65 (14.60)	24.40 (23.58)	28.74 (28.89)	23.84 (18.40)	11.03 (14.28)	6.72 (6.16)	0.00 (0.87)	125.03 (116.95)
Sunshine (20 year average)	204.5 (249.2)	167.9 (227.5)	208.0 (241.7)	232.6 (208.4)	163.9 (191.4)	185.0 (158.7)	95.9 (101.3)	66.1 (65.2)	134.0 (121.7)	226.3 (193.4)	225.1 (199.4)	257.1 (224.3)	2166.4 (2182.2)
Mean Maximum Temperature (20 year average)	89.3 (90.9)	91.0 (92.8)	91.2 (93.0)	91.8 (92.7)	90.1 (90.8)	88.3 (87.7)	83.6 (83.8)	82.4 (81.9)	85.6 (85.4)	88.2 (88.0)	88.8 (88.7)	89.7 (89.1)	88.3 (88.6)
Absolute Maximum Temperature (20 year record)	93 (102)	98 (101)	95 (102)	95 (103)	94 (101)	93 (99)	89 (98)	88 (91)	90 (99)	91 (96)	91 (99)	92 (97)	98 (103)
Mean Minimum Temperature (20 year average)	69.0 (68.3)	71.0 (69.7)	72.2 (71.6)	72.2 (73.0)	73.0 (73.5)	72.1 (72.4)	71.9 (72.1)	72.0 (72.0)	72.0 (72.3)	70.9 (71.7)	71.9 (71.8)	67.3 (69.5)	71.3 (71.5)
Absolute Minimum Temperature (20 year record)	63 (50)	65 (60)	68 (62)	68 (65)	69 (69)	68 (63)	67 (60)	67 (67)	69 (68)	68 (68)	70 (63)	58 (53)	58 (50)
Mean Relative Humidity a.m. (10 year average)	91 (88)	90 (87)	85 (84)	79 (82)	86 (84)	88 (89)	93 (92)	91 (93)	91 (92)	87 (89)	89 (89)	85 (88)	88 (88)
Maximum Relative Humidity a.m. (10 year record)	100 (100)	95 (100)	93 (100)	93 (100)	94 (100)	98 (100)	100 (100)	97 (100)	95 (100)	95 (100)	97 (100)	95 (100)	100 (100)
Mean Relative Humidity p.m. (10 year average)	55 (53)	55 (48)	56 (52)	55 (54)	75 (65)	69 (73)	83 (81)	83 (83)	74 (80)	66 (71)	67 (68)	51 (57)	66 (65)
Minimum Relative Humidity p.m. (10 year record)	32 (16)	15 (14)	40 (23)	35 (31)	47 (31)	60 (54)	65 (59)	64 (53)	64 (51)	57 (41)	56 (37)	28 (10)	15 (10)

Rainfall in inches. Sunshine in hours. Temperature in degrees Fahrenheit. Relative Humidity as percentages. Morning readings taken at 09.00 hours. Afternoon readings taken at 15.00 hours. Bracketed figures are averages and records.

APPENDIX B

RICES INTRODUCED—1959

From India

C 10022	ex Hyderabad
C 10034	ex Hyderabad
HR 67	ex Hyderabad
HR 97	ex Hyderabad
HR 98	ex Hyderabad
HR 101	ex Hyderabad
HR 103	ex Hyderabad
HR 104	ex Hyderabad
HR 105	ex Hyderabad
MTU. 9	ex Hyderabad
PLA. 2	ex Hyderabad
PLA. 3	ex Hyderabad
PLA. 4	ex Hyderabad
SLO. 19	ex Hyderabad
Sukhvel 20	
Modan Black T 1453	
A 64	
Amritsari H.S. 19	
RDR. 2	
T. 137	
Poonkar Adt. 9	
Early Sutarsar 39	
Kuruvai Adt. 3	
Swarna Sail SC. 412-56	
Maskaty 1315	
White Halga 1690	
Karsamba Red Asd. 7	
Ashkata Bankura 6	
Kele Chinsura 2	
Jhona 349	
RDR. 7	
Ram Jawain 100	
Thella Sannavadlu CO. 20	
Dharmabad 4 HR 33	
Hybrid Kuruvai Adt. 20	
Lati sail Dacca 17	
T. 136	
T. 1	
Kolaba B.R. 1	
Ch. 10	
Sarguia B.R. 2	
278 Sathari	
Kolapalla T 36	
R 10 Chhatri	

From Thailand

Jampada
Puang Ngeon E. 49

From Indonesia

Brondol Puti T 43 No. 3090
Leter 08

From Philippines

Apostol
Binacroy
Kra Suey
Buluhan
Canoni

From Cambodia

Neang Nary P 10
Neang Veng K 151

From South Viet Nam

Tieu Be R. 3
Samo R. 78

From Formosa

Kaohsiung (Takao) 27
HC 1
Chainan (Kanan) 14
Lung-yu 1804
Lung-yu 1805
Hsinchu 4

From Madagascar

No. 803

From Ceylon

Dahanala—2014
via Nigeria
Gonabaru
Allagollawa
Kothmalli Karuppan
Suduwee
Sempawala Samba
Walagambahuwa
Varangal 487
Manalwari
GEB. 24XD 325
Warneri
VI 28061
Patni 16
Zenith
Bhadas 73
Anethoda
Nallu Molli Karuppan
Godawee
Azucena
Nagdami
PTB. 29
Kinandang Puti
Tikiri Samba
Dikwee
Rexark
Satika
PTB. 28
MLY CXVI 283

From Malaya

Anak Ikan China
Pe Bi Hun

From French Sudan

Sornavari
Dissi S 290
Sossoka
Gambiaka Kokoun
Kreteck
T 141
T 1860
Ouindoun
Nioukou
Sossoka-Oule'
Gambiaka Sebela
Gambiaka Gue S 324
Kono Tana
Punasa Konomani
Koumbo S 239 B 2
Sikasso S 451 B
Nioumoun
Neang Nary
Hung-Shou-Guo-Zee

From California

Caloro Cl 1561-1

APPENDIX C

RESULTS OF EXAMINATION OF SAMPLES OF RICE FROM SIERRA LEONE AND NIGERIA

	Species and type of <i>Oryza</i>	Colour of Pericarp (Hulled Grain)	Moisture per cent	Ash per cent	Fat per cent	Protein (Nx 6.25) per cent	Total Phosphorus (as P) per cent	Calcium (as Ca) per cent	Iron (as Fe) per cent	Thiamine g/g.	Nicotinic Acid g/g.
SIERRA LEONE RICE	Gortui: Milled Raw	red	12.7	0.29	0.57	7.0	0.093	0.003	0.0010	0.63	15
	Optimum Milled Parboiled		11.0	0.64	0.38	7.5	0.162	0.003	0.0024	1.97	55
	Kebeh: Milled Raw	red	11.7	0.53	0.46	8.1	0.153	0.005	0.0012	0.97	19
	Undermilled Parboiled		11.5	0.74	0.57	8.0	0.198	0.004	0.0020	1.86	72
	Optimum Milled Parboiled		11.5	0.66	0.41	7.9	0.186	0.003	0.0020	1.83	68
	Over Milled Parboiled	white	11.4	0.61	0.30	7.8	0.155	0.003	0.0020	1.80	64
	Lead: Milled Raw		11.2	0.25	0.11	9.3	0.062	0.002	0.0009	0.32	8
	Undermilled Parboiled		10.9	0.46	0.55	10.4	0.101	0.002	0.0011	1.88	41
	Optimum Milled Parboiled		10.7	0.43	0.40	10.4	0.096	0.003	0.0012	2.20	46
	Overmilled Parboiled	white	11.1	0.43	0.35	10.2	0.099	0.002	0.0011	1.91	42
INDO CHINA 53: Milled Raw	Floating <i>sativa</i>		11.3	0.37	0.12	9.6	0.112	0.003	0.0015	0.37	12
	Bayawuri: Milled Raw	red	11.8	0.49	0.42	7.4	0.122	0.004	0.0012	0.74	21
	Undermilled Parboiled		10.4	0.71	0.50	7.7	0.169	0.003	0.0017	1.90	50
	Optimum Milled Parboiled		10.5	0.69	0.35	7.7	0.155	0.003	0.0017	1.62	49
	Overmilled Parboiled		10.5	0.66	0.38	7.3	0.150	0.003	0.0016	1.78	49
NIGERIAN RICE*	Jan Iri: Hulled	red	11.1	1.31	2.6	7.6	0.364	0.014	0.0033	2.7	66
	Milled Raw Paddy		11.5	0.55	0.4	6.4	0.124	0.010	0.0029	0.65	28
	Dan Kashi Shamu: Hulled	red	11.7	1.9	2.3	8.2	0.298	0.022	0.0024	3.6	64
	Milled Raw Paddy		10.7	0.55	0.6	7.1	0.111	0.003	0.0008	0.76	24
	B.G. 79: Hulled	white	12.2	1.24	2.7	7.9	0.344	0.007	0.0035	3.3	50
	Milled Raw Paddy		12.5	0.44	0.4	6.1	0.111	0.006	0.0024	0.77	25
	D52/37: Hulled	white	11.8	2.1	2.7	5.6	0.218	0.011	0.0008	3.4	49
	Milled Raw Paddy		11.0	0.37	0.4	4.3	0.077	0.002	0.0040	0.75	10
	Hulled Rice†	—	—	—	1.8	7.5	—	0.015	0.0014	3.3	46
	Milled Barboiled Rice†	—	—	—	1.1	7.1	—	0.014	0.0010	2.2	38
VALUES REPORTED IN THE LITERATURE	Milled Rice†	—	—	—	0.7	6.7	—	0.010	0.0009	0.8	16
	Hulled Rice‡	—	9.7	1.6	1.8	7.7	0.368	0.016	0.0040	3.6	35
	Milled Rice‡	—	9.7	0.60	0.54	6.9	0.087	0.010	0.0022	1.05	10

* Samples obtained from the Federal Rice Research Station, Badeggi, Nigeria, examined at the Tropical Products Institute 1957-1958.

† General values for rice given in "Food Composition Tables—Minerals and Vitamins", (F.A.O. *Nutritional Studies* No. 11, Rome 1954).

‡ (Bulletin Central Food Technology Research Institute, Mysore, 1956, 5, No. 14).

APPENDIX D

RESULTS OF FERTILIZER TRIALS

(a) *Subtractive bucket trial with complete nutrient*

Layout 3 plants per bucket 4 replications.

Soil ex Kontobe.

Variety Tai Chu 65.

<i>Treatment</i>	<i>Mean Weight grain per 3 plants in grams</i>	<i>Mean Weight straw per 3 plants in grams</i>
No nutrient	1.2	7.5
Total nutrient (T)	27.7	38.7
T minus Calcium	25.0	35.0
T minus Potassium	24.2	30.0
T minus Nitrogen	17.0	18.7
T minus Manganese	28.2	32.5
T minus Iron	29.5	33.5
T minus Phosphorus	1.5	8.5
T minus minor-elements	28.7	31.0
T plus Silicon	31.0	45.0
Standard error	± 1.3	± 2.3
Coefficient of variation	16.5	11.8

(b) *Additional treatments to subtractive bucket trial*

<i>Treatment</i>	<i>Mean Weight grain per 3 plants in grams</i>	<i>Mean Weight straw per 3 plants in grams</i>
Organic matter	19.4	24.3
Iron (Fe_2O_3)	22.2	30.7
Organic matter plus iron	21.7	26.4
No additional treatment	22.4	30.8

(c) *Rice growing under varying water conditions*

Layout 3 plants per bucket 4 replications.

Soil ex Rokupr. Mangrove soil of 43% field moisture capacity.

Variety Tai Chu 65.

<i>Soil moisture</i>	<i>Weight grain of 12 plants in grams</i>
10%	0.0
15%	29.0
20%	72.3
30%	65.0
40%	54.7
50%	85.6
2 ins. standing water	89.7
Critical difference (5%)	16.6
Coefficient of variation	19.0

(d) Responses to added fertilizers at Rokupr

Layout 2⁴ factorial with highest order interaction confounded. 6 replications.

Treatments Iron-rich soil (Fe) at 4 tons/acre; superphosphate (P) at 2 cwt./acre; hydrated lime (L) at 2 tons/acre; organic matter (Om) at 5 tons/acre.

Variety Radin China 4.

Plots 12 × 12 feet.

Area of plot harvested .0033 acre.

Factor	Differential responses in lb./acre				
	Mean Response	Fe	Om	P	L
Fe	100	—	56	142	52
Om	697	653	—	552	732
P	89	131	—56	—	125
L	87	39	122	123	—
Standard error for mean response					±23
Standard error for differential response					±32.5
Coefficient of variation					14.5

(e) Responses to added fertilizers at Kontobe

Layout 2⁴ factorial with highest order interaction confounded. 6 replications.

Treatments Iron rich soil (Fe) at 4 tons/acre; superphosphate (P) at 2 cwt./acre; hydrated lime (L) at 2 tons/acre; organic matter (Om) at 5 tons/acre.

Variety Parn A-191.

Plots 12 × 12 feet.

Area of plot harvested .0033 acre.

Factor	Differential responses in lb./acre				
	Mean Response	Fe	Om	P	L
Fe	18	—	19	83	—82
Om	166	167	—	180	211
P	222	287	236	—	157
L	159	59	204	94	—
Standard error for mean response					±55
Standard error for differential response					±78
Coefficient of variation					37.0

(f) Fertilizer trial with phosphate and lime at Rokupr

Layout Randomized Block 6 replications.

Treatments Superphosphate (P) at 0, 1, 2 and 3 cwt./acre, Lime (L) at 0, 2 and 4 tons/acre.

Variety Radin China 4.

Plots 12 × 12 feet.

Area of plot harvested .0033 acre.

Area of plot harvested 40055 acre.		Yields in lb./acre				
Lime	Phosphate	P_0	P_1	P_2	P_3	Mean
		Standard error ± 119				S.E. ± 59
	L_0	1,784	1,917	1,863	2,034	1,899
	L_1	1,939	2,105	1,936	2,093	2,018
	L_2	1,999	2,266	2,249	2,226	2,185
	Mean	1,907	2,096	2,016	2,118	2,034
		Standard error ± 69				
		Coefficient of variation 14.3				

(g) Fertilizer trial with phosphate and lime at Mando

Layout Randomized Block 5 replications.

Treatments Superphosphate (P) at 0, 1, 2 and 3 cwt./acre, Lime (L) at 0, 2 and 4 tons/acre.

Variety Radin China 4.

Plots 12×12 feet.

Area of plot harvested .0019 acre.

Yields in lb./acre

Lime \ Phosphate	P_0	P_1	P_2	P_3	Mean
	Standard error ± 140				S.E. ± 79
L_0	1,670	2,030	2,040	1,965	1,926
L_1	2,225	2,355	2,260	2,265	2,276
L_2	2,285	2,085	2,510	2,440	2,330
Mean	2,060	2,157	2,270	2,223	2,177
Standard error ± 89					

Coefficient of variation 15.6

(h) Fertilizer trial with phosphate and lime at Kontobe

Layout Randomized Block 6 replications.

Treatments Superphosphate (P) at 0, 1, 2 and 3 cwt./acre, Lime (L) at 0, 2 and 4 tons/acre.

Variety Parn A-191.

Plots 12×12 feet.

Area of plot harvested .0033 acre.

Yields in lb./acre

Lime \ Phosphate	P_0	P_1	P_2	P_3	Mean
	Standard error ± 39				S.E. ± 20
L_0	80	192	180	350	200
L_1	154	238	280	274	236
L_2	152	287	293	285	254
Mean	129	239	251	303	230
Standard error ± 23					

Coefficient of variation 40.5

